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Continued on page (III) of Cover

RESEARCH IN THE BRITISH POST OFFICE.

By B. S. COHEN, O.B.E., Member.

(*Paper first received* 1*st November*, 1933, *and in final form* 11*th June*, 1934; *read before* THE INSTITUTION 1*st February*, *before the* NORTH-WESTERN CENTRE 20*th March*, *before the* NORTH-EASTERN CENTRE 9*th April*, *and before the* SCOTTISH CENTRE 10*th April*, 1934.)

SUMMARY.

It is proposed to outline the activities of the Post Office in telecommunication research. It is not proposed, however, within the limits of this paper to deal with radio work. Description of the Dollis Hill Research Station with regard to the lay-out, buildings, and organization, is followed by details of thevarious research groups. So far as possible, the paper is confined to descriptions of principles and methods involved in carrying out the various types of investigations, and, in general, details of individual researches are omitted. In a few specific cases, however, it has been considered desirable to give certain details in order to convey some indication of what is involved in telecommunication research. The paper deals primarily with the period since the establishment in 1921 of the Dollis Hill Research Station. In order, however, to complete the picture, it is desirable in the first place to refer briefly to the period prior to 1921.

HISTORICAL DEVELOPMENT OF POST OFFICE RESEARCH.

When the State purchased the telegraphs in 1869 the number of electrical workers in the whole country could be counted almost on the fingers; to-day the Engineer-in-Chief of the Post Office controls a staff of about 30 000 and maintains plant of a value of £130 millions. For the evolution of the telegraph from the 5-needle and double-needle instruments to the high-speed Wheatstone, many skilled P.O. experimentalists were responsible—men like Stroh, Preece, Cooper, Kempe, Chapman, Willmot—and, in spite of the limited facilities and almost entire absence of external information at their disposal, such instruments as the P.O. standard telegraph relay and the Wheatstone transmitter and receiver were developed. These instruments are capable of operating up to speeds of over 300 words per minute, and still stand unsurpassed to-day in their design, workmanship, and performance.

In the early days, even after the purchase of the trunk system, the Engineer-in-Chief's staff—quite a small body of men—had to pursue their ordinary administrative vocations. It was not till 1904–5 that one or two men were set aside to pursue investigations that gave indication of being prolonged in character. At that time the National Telephone Co. installed in Telephone House a laboratory which was entirely devoted to telephonic research. Some of its early work in transmission was covered by the paper read in 1907 before this Institution by the late Mr. G. M. Shepherd and the present author.* As Parliament in 1905 settled the length of the life of the Company, the two administrations began to take friendly notice of each other. Combined speaking tests were carried out and in 1906 a telephone standard of reference was agreed and set up. The experimenting room at the south-east corner of the G.P.O. West was used indiscriminately by all sections at headquarters under the jurisdiction of Mr. H. R. Kempe.

In 1912 a Research Section was established as a permanent branch of the headquarters organization under the charge of Mr. Kempe. The laboratories of the National Telephone Co. were transferred from Telephone House to the top floor of King Edward Building and were embodied in the Research Section, and the combined staffs distributed in order to deal with the various telephone line and apparatus problems, loading coils, telegraph matters, and with all the multifarious problems involved in the rapid development of the services of the Department. Then came the War period, in which the conditions were abnormal. During this period a great part of the staff was allocated to War research. The perfecting of the thermionic valve during the War period made the telephone repeater practicable and at one stroke opened a boundless vista of possibilities in the way of universal telephonic communication. The arrears of work in the Engineering Department, which had accumulated during the War years, were taken in hand as the men came back, and the development of the services was pushed forward. Underground schemes, both main trunk and local distribution, were evolved, repeater stations were designed and installed, automatic switching made rapid headway, and telephone rates were revised and placed on a paying basis. The space and facilities afforded by the experimenting room in the G.P.O. West became inadequate to meet research requirements.

The extent to which the Post Office should embark on a general programme of telecommunication research required and received very careful consideration. Whilst it is not proposed to discuss in this paper the many cogent reasons for the research policy of the Post Office, it is thought well to mention here the paramount necessity for the closest co-ordination between the research and operating organizations, so that full access for research purposes can be had to the working telephone and telegraph plant and circuits. The Post Office, as an operating organization, is naturally primarily concerned with research in connection with the design, operation, and maintenance, of electrical communication plant, leaving research in connection with the construction of plant to the manufacturers.

DOLLIS HILL RESEARCH STATION.

In 1920 a site of 8 acres was purchased by the Post Office on which to build a station equipped to deal with all branches of communications-engineering research. The establishment of a research station on this suburban site in North-West London was due to a great extent to the initiative of Mr. S. A. Pollock.

At that time the cost of erecting the permanent buildings would have been excessive, and a certain amount of experience was also desirable in order to be certain of the most suitable lay-out and type of building required. A start was therefore made in 1921 with a number of ex-army huts suitably converted into laboratories, workshops, and offices. These hutments, originally designed to serve for about 5 years, have only been withdrawn from use during the past 2 years.

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* B. S. COHEN and G. M. SHEPHERD: "Telephonic Transmission Measurements," *Journal I.E.E.*, 1907, vol. 39, p. 503.

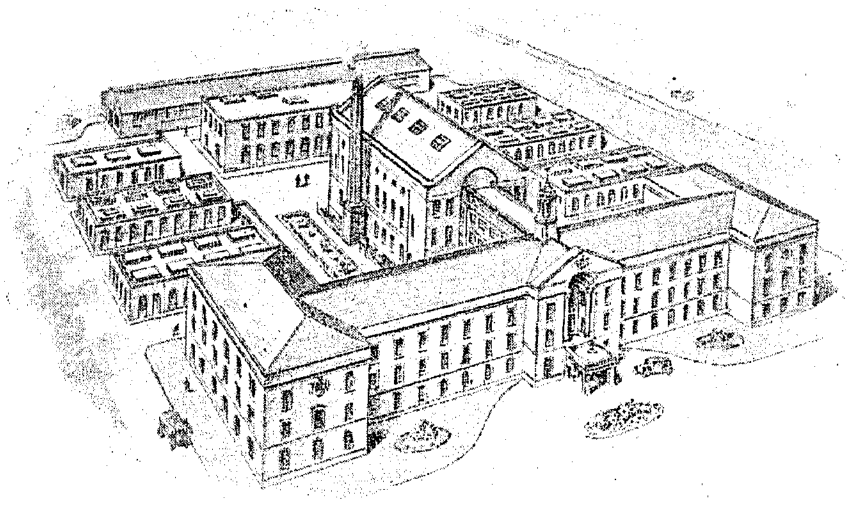


Fig. 1.—P.O. Engineering Research Station, Dollis Hill.

Permanent Buildings.

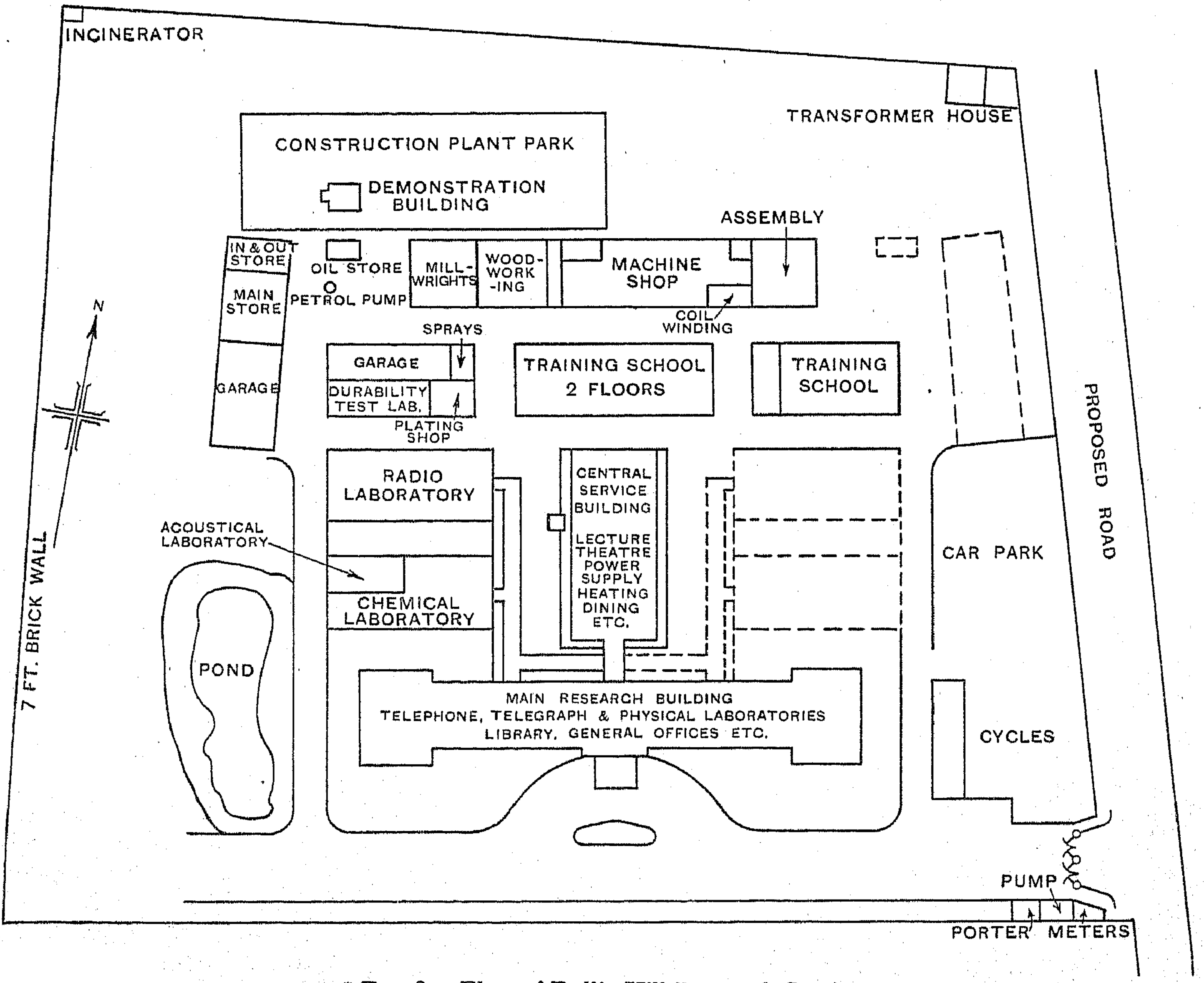
These buildings were designed by Mr. A. R. Myers, the Office of Works architect, and, in addition to incorporating every research requirement, may be regarded as of real beauty.

Fig. 1, from a perspective drawing, gives an indication of the arrangement of the various buildings. This does not, however, show a garage and stores building since added, and the two lower right-hand outlying buildings are not yet built. The allocation of the various buildings can be seen from the key plan (Fig. 2).

The Dollis Hill Station, in addition to being the research centre for the Post Office, is also the technical training centre for the Engineering Department. Space will not permit the author to deal with the extensive training activities, but the accommodation devoted to this purpose is shown in the key plan.

Figs. 3 to 5 show the allocation of laboratories and offices, etc., on the three lower floors of the main building. Particulars of the outlying laboratory buildings will appear under the appropriate research group headings. A general outline of the lay-out for the main building is given here.

The main research block consists of a building some 286 ft. long with three principal floors. On the centreline of this building and projecting beyond the main frontage is a *porte cochère* of brick and stone, on the lintels of which are incised the words " Research is the Door to To-morrow " and " To Strive, To Seek, To Find." On the ground floor are the offices of the administrative and clerical staff. The western end is occupied by laboratories for physical and special electrical investigations, and the eastern end is given over to work on exchange signalling methods and apparatus. At the western end



* Fig 2.—Plan of Dollis Hill Research Station.

* The author is indebted to H.M. Stationery Office for the loan of the block for this Figure

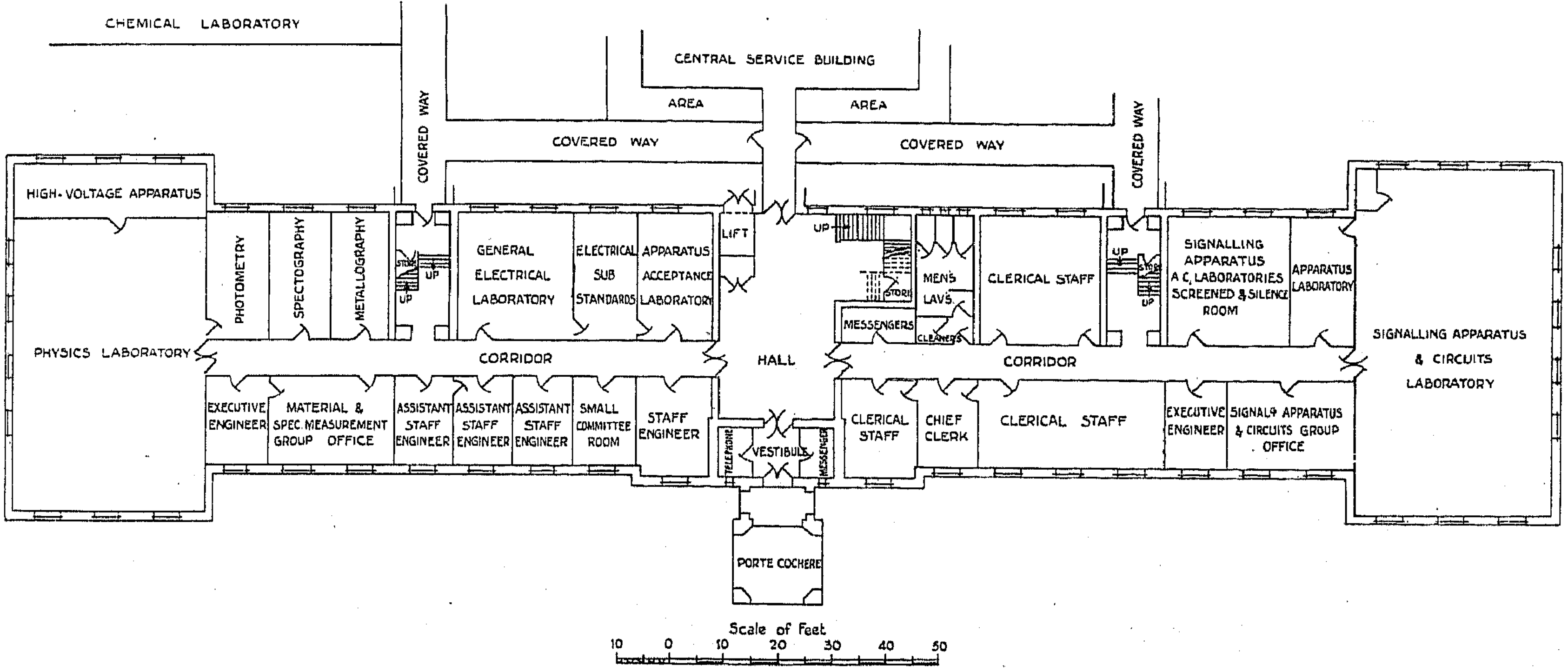


FIG. 3.—General research building: ground floor.

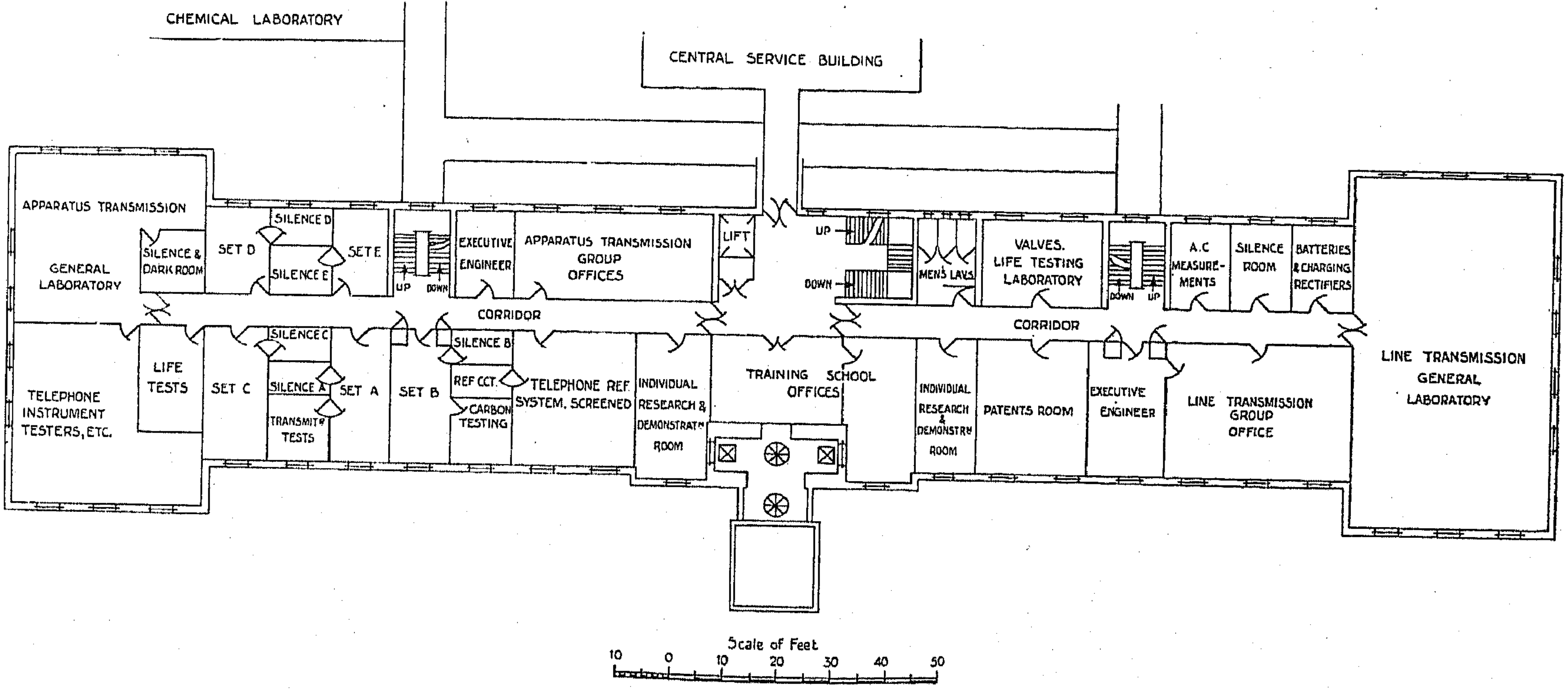


FIG. 4.—General research building: first floor.

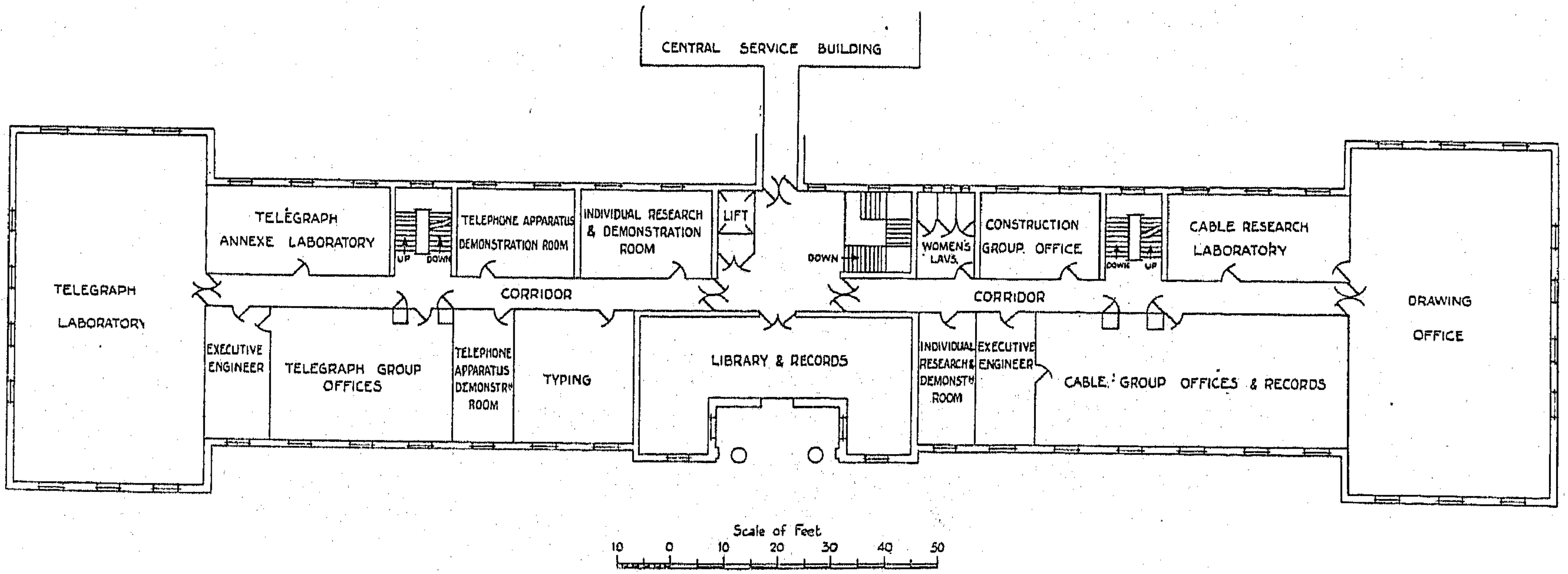

CENTRAL SERVICE BUILDING
TELEGRAPH LABORATORY
TELEGRAPH ANNEXE LABORATORY
UP
DOWN
TELEPHONE APPARATUS DEMONSTRATION ROOM
INDIVIDUAL RESEARCH & DEMONSTRATION ROOM
LIFT
DOWN
WOMENS LAVS
CONSTRUCTION GROUP OFFICE
DOWN
UP
CABLE RESEARCH LABORATORY
DRAWING OFFICE
CORRIDOR
CORRIDOR
EXECUTIVE ENGINEER
TELEGRAPH GROUP OFFICES
TELEPHONE APPARATUS DEMONSTRN ROOM
TYPING
LIBRARY & RECORDS
INDIVIDUAL RESEARCH & DEMONSTRN ROOM
EXECUTIVE ENGINEER
CABLE GROUP OFFICES & RECORDS
Scale of Feet
10 0 10 20 30 40 50

FIG. 5.—General research building: second floor.

of the first floor (Fig. 4), apparatus transmission measurements are made. The specially silenced laboratories used for some of this work are ventilated by a system connecting to a ventilating flèche on the roof. This is crowned with a wind vane, the design of which is symbolical of the world-wide use of electricity in telecommunication. The laboratories at the eastern end of this floor are used for research on line transmission problems. The telegraph laboratories occupy the western end of the second floor (Fig. 5). In the centre of this floor is the library, a rectangular room with a vaulted ceiling. The general lighting of this room is indirect, being effected by means of lamps placed out of sight above the plaster cornice. At the eastern end of the second floor are accommodated a group dealing with cable tests and research, and a design and construction group. The central block accommodates, on the lower floors, the heating and power services, staff refreshment rooms and kitchens, and two basement laboratories for mechanical testing. On the second floor is the lecture theatre, a spacious room used for a variety of purposes such as conferences and lectures to large classes. Round the walls are tables with working exhibits of various recent research developments, and there is a sound-film projecting equipment. On this floor also are rooms devoted to teleprinter training, whilst on the top floor of this building, together with part of the top floor of the main research building, are the photographic studios.

The independent single-storey laboratories east and west of the central block are connected with the latter and with the main building by covered ways.

Separated from the central block by a roadway is the Automatic Training School building of two storeys, and farther to the north lies the workshop, arranged in a building some 240 ft. long and 40 ft. wide. The remainder of the station to the northward is occupied by the construction park—laid out for research and training in connection with the various processes involved in the outdoor activities of the Post Office engineering staffs.

The whole of the laboratories are connected to the central block, from which is drawn the power essential to the working of the station, by means of horizontal ducts formed above the covered ways and above or below the corridors, and connected vertically so that all services may be laid to the rooms without being observed.

A number of rooms and laboratories have been specially treated with acoustic plaster and other sound-absorbing materials. The finish of these rooms in various ways is a special feature of the arrangements at this station.

The permanent research-station buildings have a total superficial area of over 107 000 sq. ft.

Electric Supply, Laboratory Services, and Fittings.

Electric power for the Research Station is purchased on a maximum-demand basis from the Willesden Borough Council. The 2 000-volt, 3-phase supply is transformed down to 415 volts. Thirteen motor-generator sets are installed in the generator room to provide d.c. supplies and for charging the batteries, also two Duddell alternators and two ringing machines. The majority of d.c. supplies to the laboratories are obtained from batteries, of which there are 12 in the battery room, ranging in size from 40 to 1 000 ampere-hours. The batteries are of various types so that comparison may be made, under working conditions, of the products of different manufacturers. The main voltages distributed are ± 22, 40, 50, 100, 150, and 240 (d.c.), and 240 (a.c.).

The main cabling and laboratory wiring has been provided on a basis of a maximum voltage-drop, battery to bench panel, at full load on the main feeds, of not more than 2 volts on voltages up to 100, and 5 volts on 100 and over. Even so, it is not certain that the variation on some of the supplies will be small enough to meet all requirements, and for certain laboratories special arrangements have been made by the provision of batteries in, or adjacent to, the laboratory. These battery equipments include rectifier sets for charging from the a.c. supply. An example is the battery room shown in Fig. 4 adjacent to the line transmission laboratory and used in connection with repeater and carrier research, etc. The batteries in this room also form the subject of an experiment themselves, as the electrolyte of various cells is covered with different kinds of oil to determine their relative efficiency for preventing acid spray and their comparative effect on the cells.

In the main research building the laboratories are grouped in eight divisions, and in each division there is a main distribution board which is cabled to the central switching point. In the laboratories the cabling is run through floor chases and double-top benches, so that convenient access may be obtained at all points. Bench panels with switch and terminal arrangements are provided at convenient points.

In addition to the power supplies, junction circuits are provided to each panel. From the eight distribution boards, circuits are also provided to a central junction board so that panels in different groups may be connected to one another. At this central board are also terminated direct lines from Gladstone Exchange and a 24-pair loaded cable from Trunk Exchange. By the use of the inter-laboratory junctions it is thus possible for a direct connection to be established from a bench panel either to Gladstone or to Trunks for experimental work. The cable to Trunks has 10 pairs loaded with 22-mH coils at 2 000 yards' spacing, thus giving a cut-off exceeding 7 000 cycles per sec., and in consequence these pairs may be used to connect up to high-quality circuits.

Cupboards of two standardized types are provided for the storage of apparatus, specimens, etc. The smaller of these cupboards is provided with glazed doors and fits conveniently under the laboratory benching.

Special Services in Central Block.

The telephone exchange is situated on the second floor of this building. A locator system is worked in conjunction with the P.B.X. to secure connection with certain members of the staff when not available on their normal extensions. To attract their attention the operator dials a code number: this causes numbered lamps to flash intermittently on indicator boards, installed at various points, and indicates to the desired person that a call is waiting for him. The master clock for the electric clock system of the station is also installed in the exchange room.

The greater part of the first floor is given over to dining accommodation for the staff. The total number of persons employed or in training at the station often exceeds 600, and there is no accommodation capable of dealing with such a number within a mile of Dollis Hill. Dining-room and kitchen accommodation is therefore provided here for a financially self-supporting refreshment club.

Research Workshops.

To deal with the construction of experimental apparatus, a group of fully equipped workshops is maintained, with a staff of highly skilled instrument makers, woodworkers, etc. These shops are of considerable importance, as they are used to construct not only any special items required for carrying out researches, but in addition the first models of instruments, systems, etc., resulting from researches, many of which are brought ultimately into universal use in the telephone or telegraph service. The main block of workshops includes assembly, coil-winding, machine, woodworkers', and millwrights' shops, housed in one building situated behind the training school. At one end of the adjacent durability laboratory, rooms are allocated for electroplating and paint-spray work.

Small-Job Workshop.

Difficulty has been experienced in most research organizations when the construction of special apparatus arising as a result of investigation is entirely centralized, as there is always a tendency for individual research groups to obviate delay caused by passing the simpler mechanical jobs to the central workshops, by carrying out such work in a corner of the laboratory. This has been met in some research organizations by providing individual workshops to the groups, the central workshop dealing with the larger items only. It is considered, however, that this results in a tendency to construct major items in the group shops, leading to lack of uniformity and co-ordination.

At Dollis Hill this difficulty, it is thought, has been met by setting up a small-job workshop, on the top floor of the main research building, which is accessible to any member of any group and which is provided only with simple tools such as vices, files, drills, saws, and so forth.

Construction Park.

The construction park, an area of some 12 000 sq. ft. situated behind the workshop block, is partly used for research in connection with external construction, both overhead and underground, and also for the purpose of training men and youths in the handling of tools and appliances used in connection with external construction and maintenance work. In this open space a standard pole route is provided and used for training in the erection of open wire and in regulating, tree-cutting, staying, etc. A number of short poles are also erected for practice in pole climbing, and to show the methods of moving and recovering poles. Arrangements have been made for the poles to be armed near ground-level, so that classes may be given demonstrations of wire-jointing, regulating, transposing, and the use of special tools.

The underground plant installed consists of a multiple-way duct route and cast-iron pipe, with manholes and jointing boxes of the usual type, and is used for demonstrations in cabling and jointing operations. This duct route has recently also been used for research work in connection with the accumulation of gas in manholes, and for work on cable-sheath electrolysis. An interesting investigation has recently been commenced in connection with the creepage of cables in ducts under roads carrying heavy vehicular traffic. Cases have occurred where large cables have moved forward in the ducts to an extent sufficient to cause a serious kink in the cable at the manhole, the direction of movement being almost invariably in the same direction as the predominating traffic-flow, even in some cases uphill. Experiments on new types of line wire have been also made under practical conditions on the pole routes.

Organization.

It has been necessary to organize the staffing of the Research Station on the same lines and using the same grades as that of the Post Office Engineering Department as a whole. Although certain difficulties have arisen in adapting the engineering grades to research workers, it is thought that in the main these difficulties have been successfully overcome.

The station is under the control of a staff engineer who acts as director of research and is directly assisted by three assistant staff engineers. The research work is divided into eight groups and there is a ninth group devoted to technical training. Each assistant staff engineer deals with three of these groups.

Each group, with the exception of the editorial, is directly in charge of an executive engineer, and the two sub-groups are also controlled by executive engineers.

The organization is shown in some detail in Fig. 6. Detailed charts for two of the individual research groups will be found under their appropriate headings.

The actual research staff consists of 112 major ranks, i.e. staff and assistant staff engineers, executive engineers, assistant engineers, and chief inspectors and inspectors, together with a clerical force under a staff officer, and 174 minor staff, including skilled workmen, telephonists, labourers, etc. There is in addition a staff of 73 employed on technical training.

Stores and Storekeeping.

After some years' experience with various methods of storekeeping a method has now been adopted which possesses many advantages for the particular requirements to be met. Each technical group holds all the specialized apparatus essential to its own work, together with any general apparatus such as measuring instruments, etc., which are in constant use by the group, one of the staff of each group being held responsible for the custody and maintenance of the various items. There is, in addition, a general store holding consumable items and materials, including all materials required by the workshops for the construction of models, together with a stock of tools, and an " in and out " store at which all new items are delivered

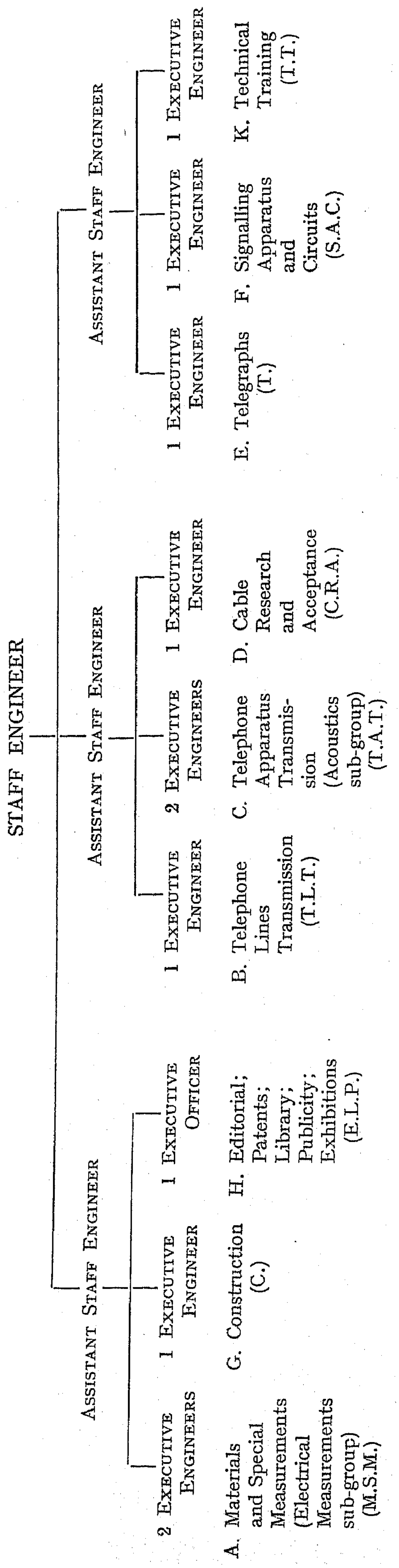

STAFF ENGINEER
ASSISTANT STAFF ENGINEER
2 EXECUTIVE ENGINEERS
A. Materials and Special Measurements (Electrical Measurements sub-group) (M.S.M.)
1 EXECUTIVE ENGINEER
G. Construction (C.)
1 EXECUTIVE OFFICER
H. Editorial; Patents; Library; Publicity; Exhibitions (E.L.P.)
ASSISTANT STAFF ENGINEER
1 EXECUTIVE ENGINEER
B. Telephone Lines Transmission (T.L.T.)
2 EXECUTIVE ENGINEERS
C. Telephone Apparatus Transmission (Acoustics sub-group) (T.A.T.)
1 EXECUTIVE ENGINEER
D. Cable Research and Acceptance (C.R.A.)
ASSISTANT STAFF ENGINEER
1 EXECUTIVE ENGINEER
E. Telegraphs (T.)
1 EXECUTIVE ENGINEER
F. Signalling Apparatus and Circuits (S.A.C.)
1 EXECUTIVE ENGINEER
K. Technical Training (T.T.)

FIG. 6.—Research Section Organization—Technical Groups.

and from which recovered and scrapped items are returned to the stores department.

The overall value of the Research Station's plant exceeds £100 000, and in addition to this there is a valuable and variable stock of consumable stores and materials.

Financial Aspect of Research.—The Research Department forecasts annually its general expenditure on staff, plant, and materials, special authority being obtained, as necessary, for expenditure exceeding a certain amount in any individual case.

Schedules of running costs are maintained in connection with each case, so that the amount spent is constantly under review.

It may be taken as axiomatic that it is generally impracticable to estimate the value of pure research in terms of pounds, shillings, and pence. In the case of a research station such as that of the Post Office, which deals mainly with applied research, this does not necessarily hold, and experience has proved that it is possible to produce an annual balance sheet showing expenditure and revenue accruing from a selected number of the cases dealt with. The number of investigations increased from 370 in 1927–8 to 511 in 1932–3. During the latter year, 14 of the more important cases dealt with were of the type for which the revenue accruing could be adequately assessed, and these 14 cases result in either increased annual revenues or savings to the Department, amounting to a sum more than double the total annual expenditure on research.

Space will not permit the author to enter into details, but the cases selected range from the introduction of a new voice-frequency signalling system to methods of localizing submarine cable faults by means of electrodes towed from a cable ship. In addition to the large and ascertainable savings resulting from the application of these 14 investigations, there is the probably considerably larger but unascertainable saving resulting from the remaining 497 investigations.

To give some idea of the range of the work, the various investigations carried out can be tabulated under the following headings:—

General electrical (d.c. and a.c.), physical, chemical, and metallurgical.

Interference.

Protection, including electrolysis of underground cables.

Insulating materials.

Telephone repeater and carrier systems.

Voice-operated switching devices, including echo-suppressors and stabilizers.

Maintenance of telephone transmission standards.

Transmission characteristics of telephone instruments, circuits, and apparatus.

Acoustical and electro-acoustical investigations and measurements.

Cable investigations, tests, and faults.

Automatic and manual telephone-exchange signalling and impulsing, using direct and alternating current.

Investigations of telephone signalling apparatus requiring measurements of impedance, noise, cross-talk, etc.

General investigations of automatic and manual switching apparatus, including life tests.

Voice-frequency telegraph working.

Telegraph apparatus and circuits other than teleprinter.

Teleprinter investigations—distortion and operating characteristics.

Progress of Investigations : Research Reports.

The continual growth in the number of investigations demands ever-increasing care in maintaining a close watch over their progress, together with ensuring effective co-ordination at all stages both between the research groups and between the Research Station and other sections of the Engineering Department. This is made possible by the system finally evolved, a brief description of which is given here.

Every investigation, whether emanating from another section or department or initiated at the Research Station, is at the outset allotted a case number against which the necessary details are recorded. This number identifies the investigation until it is brought to a conclusion, and particulars are furnished to the group or groups concerned.

At fortnightly intervals lists of the new cases, giving brief details, are prepared for the information of administrative staff and for circulation to the groups. In addition each group supplies a return of the cases on which it has been working, showing the stage reached in each investigation. By these means it is possible to secure effective co-ordination within the section at the outset and to maintain the progress of the investigations under constant review. Further, a Co-ordinating Committee dealing with research and development, and with representatives of all the headquarter sections of the Engineering Department, meets at approximately three-weekly intervals. The Department as a whole is thus able to maintain close touch with any new developments within the functions of research. An internal Co-ordinating Committee comprising the administrative staff and the research-group heads meets at intervals to discuss any matters of general importance to the Research Station and to decide how to deal with those researches which require collaboration between two or more groups.

Each investigation, at its conclusion, is normally made the subject of a report, which bears the original case number. The reports, together with most of the associated diagrams and photographic illustrations, are prepared by a duplicating process giving good reproduction and admitting of the printing of any number of copies within reasonable requirements. Apparatus for binding the reports, etc., is installed in a room on the roof floor of the main research building. The majority of the reports are circulated throughout the Department and, in addition, a considerable number are sent to the various Service departments, Colonial and Foreign Administrations, and other interested bodies. Evidence is held that these departments and bodies find the information given of considerable value, and in return much interesting material is obtained from them.

Co-operation with other Research Organizations.

No attempt is made to carry out any research or portions of a research at the Post Office Research Station which might be better carried out in some other research laboratory. For example, investigations into acoustics of building materials are delegated to the National Physical Laboratory, as also are fundamental electrical calibrations, although to save time a series of sub-standard electrical measuring instruments is installed for secondary calibrations. Again, any purely chemical investigation which does not involve some problem specific to electrical communication is referred to the Government Chemical Laboratory. In connection with other specialized investigations, considerable use is made of the work of such research organizations as the British Non-Ferrous Metals Research Association, the British Electrical and Allied Industries Research Association, the Forestry Products Research Laboratory, and the Building Research Station. As previously mentioned, research work in connection with the construction of telecommunication apparatus is primarily dealt with by the various research laboratories attached to the manufacturing organizations, and the Post Office is always in close touch with these laboratories. Considerable use is made of the Dollis Hill Station by many of the Service departments and by various Colonial Administrations.

Telecommunication Research Abroad.

Much could be written on this subject, but it is proposed to refer here only to the U.S.A. and Germany. The world centre for telecommunication research is the large building in West Street, New York, which was formerly the Western Electric Co.'s factory and now houses the major part of the Bell Laboratories. From this building have issued many important developments in the art of telecommunication and such allied subjects as sound recording and talking pictures. In the United States, the operating and manufacturing companies are allied organizations under the control of the American Telephone and Telegraph Co. This, whilst extending the field of research and development, has also tended towards simplification in policy.

The American Telephone and Telegraph Co. spend about 1 dollar per annum per subscriber's station on research, as compared with the British figure of approximately 9½d. The Bell Laboratories building is admitted to be far from ideal for all branches of telecommunication research, and a number of outlying laboratories in and around New York have had to be set up. A scheme for a specially designed research station about 30 miles outside New York has been under consideration for some time.

The German Reichspost have a large research building, the Reichspostzentralamt, in Charlottenburg, which also houses other branches of the engineering and stores administrations. The firm of Siemens and Halske works in very close touch with the German Post Office and carries out a considerable amount of research for it. Another important research organization in Berlin which deals both directly and indirectly with telecommunication is the Heinrich Hertz Institute, whose world-famous director, Dr. K. W. Wagner, was in a great measure responsible for the inception and design of the Reichspostzentralamt.

Having given a description of the Dollis Hill Station and organization, the author now proposes to devote the remainder of the paper to a description of the individual research groups, together with particulars of the classes of work on which they are engaged.

A. MATERIALS AND SPECIAL MEASUREMENTS GROUP.

Fig. 7 indicates the organization of this group, which is directly concerned with the quality and preservation of all the engineering materials incorporated in the telephone and telegraph plant. New alloys, dielectrics, finishes, treatments, etc., are constantly being investigated with regard to their utility to the engineering service.

The laboratories associated with this group are as follows:—

Metallographic, spectrographic, photometric, and main physics laboratory, on the ground floor of the main building. The last-mentioned laboratory has a screened-off portion devoted to investigations requiring high voltages, and included in this portion is X-ray apparatus and apparatus for tests of lightning arrestors, etc. An impulse generator producing instantaneous discharges of about 250 000 volts, on the lines of the larger one installed at the National Physical Laboratory, has just been set up here and is expected to prove of considerable use in connection with investigating the effects of direct lightning discharges on subscribers' telephone apparatus, and so forth.

Other laboratories associated with this group are the chemical laboratory in an outlying building (see Fig. 2) and the mechanical laboratory in the basement of the central building. The electrical measurements subgroup of this group has three electrical laboratories on the ground floor of the main building (see Fig. 3).

Chemical.

The advice of the group is sought on a wide diversity of questions, some of which lie outside the purely electrical side of communications; for instance, the transmission of volatile liquids, etc., through the mails. Generally, however, the problems submitted demand that the chemists shall be thoroughly cognisant of current developments in the materials incorporated in electrical communication apparatus. A recently completed investigation into methods of testing enamelled wires was undertaken to ensure that the Department obtains the improved quality of wire which the industry is capable of supplying, and involved a very thorough study of the properties of enamelled wire of all types.

The increase in the volume and weight of road traffic has brought with it a new problem. There are, apparently, under the streets an ever-increasing number of cracked gas mains. Modern road surfaces make it difficult for this gas to escape into the open, but it does accumulate in Post Office cable ducts and manholes, involving a serious hazard. Research Section chemists have developed a simple form of gas detector for general issue to Post Office workmen. This detector, Fig. 8, operating somewhat after the manner of a photographic exposure meter, but utilizing a filter paper moistened with a few drops of palladium-chloride solution, will indicate the presence of 0·05 per cent of carbon monoxide, the dangerous constituent of coal gas.

According to Sir Robert Hadfield, the corrosion of iron and steel alone costs the world £700 millions per annum. The protection of indoor telephone plant

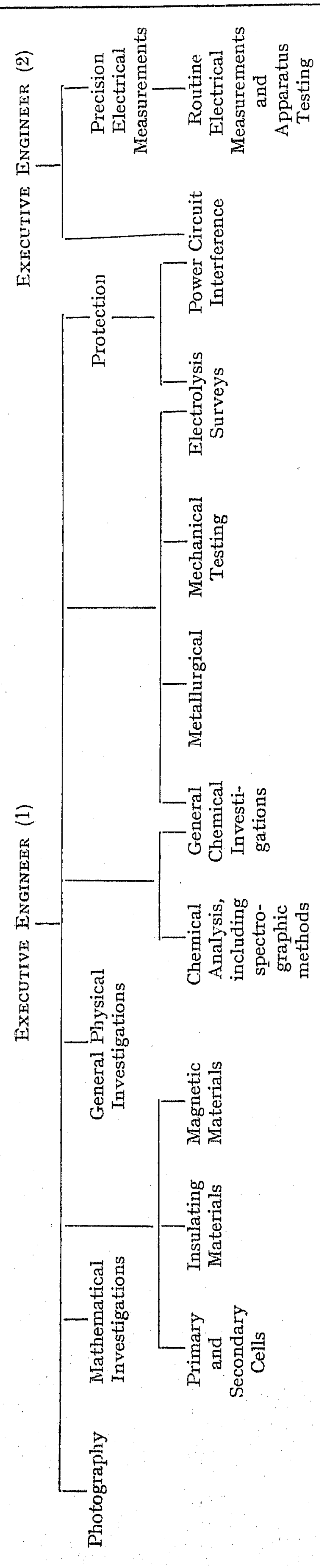

EXECUTIVE ENGINEER (2)
Precision Electrical Measurements
Routine Electrical Measurements and Apparatus Testing
Power Circuit Interference
Protection
Electrolysis Surveys
Mechanical Testing
Metallurgical
General Chemical Investigations
Chemical Analysis, including spectrographic methods
EXECUTIVE ENGINEER (1)
General Physical Investigations
Magnetic Materials
Insulating Materials
Primary and Secondary Cells
Mathematical Investigations
Photography

FIG. 7.—Materials and Special Measurements Group.

against corrosion has become more important as the capital value of automatic switching apparatus installed in exchanges has increased. The Research Section investigates the various finishes, etc., available for the purpose, by means of a series of three corrosion spray chambers. Specially designed jets fill the three chambers with "artificial fogs" consisting respectively of water, together with products of gas combustion, dilute sulphuric acid, and salt solution. Sample parts are suspended in the fogs from arms carried by slowly-rotating, vertical, stainless-steel shafts. Effects are produced in a few weeks which would correspond to very many years' life in the atmosphere of a telephone exchange. As regards the corrosion of external plant, field tests are being carried out at 14 different stations in the country on the corrosion of galvanized-iron stay-wires. The experimental results indicate that the life of the wire is in general a linear function of the thickness of the galvanizing, and, although the tests are scheduled to run for another three years, it is already possible to estimate the life of any particular grade of wire in a given area. In some parts of South Lancashire the normal life of a stay wire is little more than 2 years.

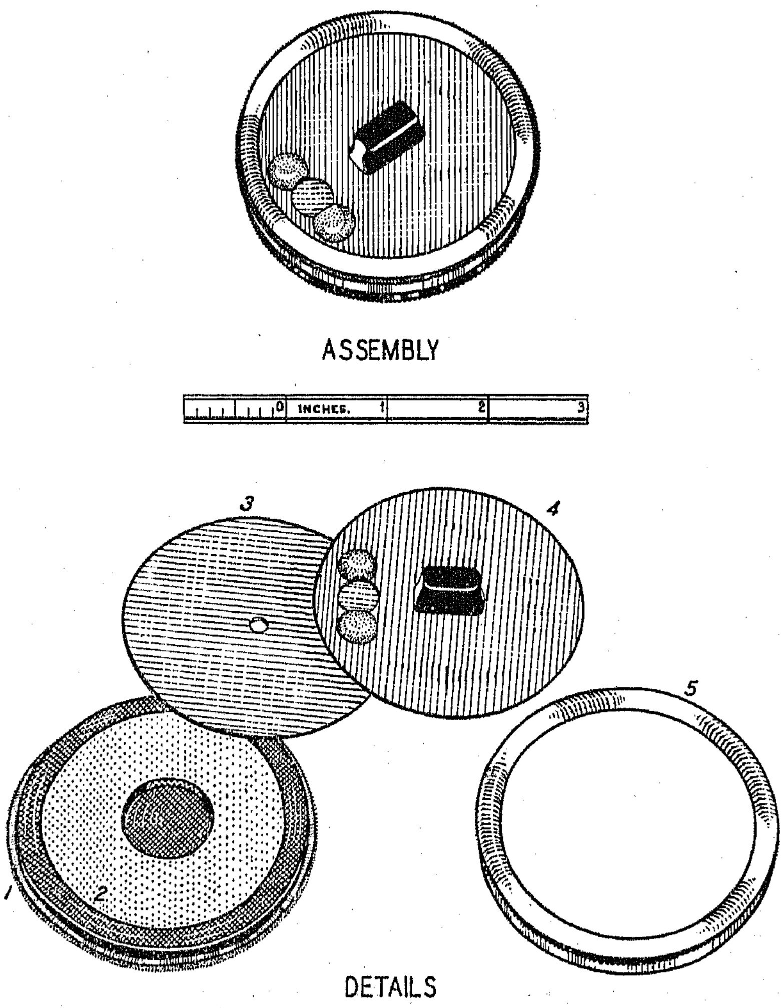


FIG. 8.—Palladium-chloride indicator for carbon monoxide.

Corrosion of the lead sheaths of telephone cables by contact with soil and water is another important problem. Protective wrappings have been tried in bad areas, but these greatly reduce the ease with which bare cables are drawn into and out of the ducts. Laboratory research on small samples resulted in the suggestion that certain compounds might act as inhibitors of chemical corrosion by the formation of protective films, and one of these, sodium silicate, is now being given a practical trial in the field. It is applied by mixing with the petroleum jelly used for lubricating the cable when drawing into the ducts, and seems likely to give helpful results.

Physics.

Use is made of all modern developments in methods of examining materials, and laboratories are devoted exclusively to spectrographic and metallographic work. In addition, early use was made of the X-ray spectrograph and, although the technical applications of this method have not yet been fully explored by industry, Research Section physicists are conversant with its use and some of its possibilities. It has, for example, been used to attack the problem of the carbon granule used in telephone transmitters where more ordinary methods of investigating minute structural differences break down. It may be mentioned that irregularities in ring patterns, obtained by reflection of the incident beam through nearly 180°, were being investigated in the Research Section before cameras for this method of working were generally available.*

Spectrographic.—Early spectrographic work was of a qualitative nature and concerned with such parts as thoriated-tungsten valve filaments, relay contacts, etc. In each case the smallness of the sample available for investigation emphasized the usefulness of the spectrographic method. Qualitative spectrographic analysis depends on the recognition of lines characteristic of each element in the spectrum of the light emitted from an arc, or spark, between electrodes of the material under examination. A quantity as low as 0·00015 per cent of copper in lead may be detected in this way. However, when the electrodes contain one constituent in comparatively small proportions, the intensity of the spectral lines due to that constituent is proportional to its concentration. This forms a basis for quantitative spectrographic analysis and, about 2 years ago, as a result of research in the Post Office laboratories, it began to be possible to express results quantitatively. A short description of the method may be of interest. A disc is rotated in front of the spectrographic slit. The periphery of this disc is shaped in the form of a logarithmic spiral so that light from the arc, or spark, enters at the top of the slit for 100 times as long as it does at the bottom. The resultant effect is that on the photographic plate the spectral lines appear varying in length according to their intensity. Hence the length of a spectral line due to a minor constituent will be a measure of its concentration in the material of the electrodes. Actually, determination of the percentage of the minor constituent is made by measuring the difference in length between a selected line due to the minor constituent and an adjacent line due to a major constituent. Comparison with an "internal standard" in this way eliminates the effect of small variations in exposure and development which affect both lines together.

The first alloy for which calibration data were obtained was the lead-antimony alloy used for sheathing aerial cables (0·8 to 1 per cent Sb). Tin and cadmium in lead were next dealt with, thus providing data for the rapid quantitative assay of the binary and ternary alloys used for cable sheathing. Fig. 9 shows the quantitative spectrographic determination of antimony in a lead-antimony alloy.

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* W.G. RADLEY: "X-rays and the Structure of Some Engineering Materials," Institution of Post Office Electrical Engineers, Paper No. 121, 1929.

The Post Office may claim to have taken a leading part in the development of this modern method of analysis, and to have introduced it to cable manufacturers. While the method has certain limitations, the figure obtained spectrographically is sufficiently definite to be within the practical limits of accuracy required. A great advantage is that the simplicity and speed with which spectrographic assays can be carried out facilitate a more frequent examination and result in a closer control of purity and uniformity.

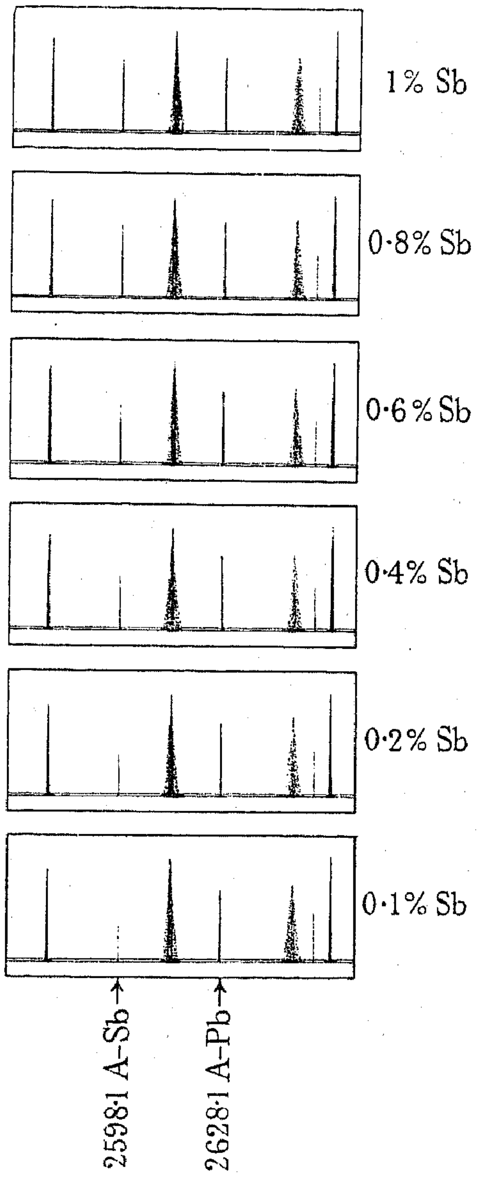

Fig. 9.—Spectra of lead-antimony alloys taken with logarithmic sector.

Metallurgical.—The metallurgical microscope has been firmly established in the Research Section since pre-war days. Valuable pioneer work in connection with extrusion faults in lead-sheathed cables was done with it.

A small laboratory, equipped with two metallographs, is so arranged that the final polishing and etching of the samples is carried out in the same room, thus making for ease and speed of working. Work at high magnifications, up to 1 000 diameters or more, may be called for in connection with the investigation of steels, etc., but for a large number of problems that find their way into this laboratory an examination at a magnification of 200 or 300 is sufficient. For the examination of corrosion or fatigue faults on cable sheaths, etc., considerable use is made of the Greenhough binocular microscope at magnifications of from 10 to 50 diameters.

Mechanical Testing.—Much of the metallographic work is linked up with that done in the mechanical testing laboratory. This is equipped with standard machines for making tensile, hardness, and impact tests, and, in addition, with machines constructed in the Research Section workshops for the purpose of measuring the fatigue resistance of line wires (rotating cantilever type of machine), spring materials, etc. As an instance of the work done in this laboratory, that on nickel-silver, of which more than 500 tons are in use by the Department in the form of the springs on telephone relays, may be mentioned. The mechanical properties of nickel-silver are vital to the successful operation of telephone relays. On them depend ability to adjust relay springs, combined with correct contact pressure.

Dielectric Research, etc.

Electrical as well as mechanical properties of the various insulating materials used in telephone apparatus are studied by this group. The electrical measurements made follow very closely on the lines of those carried out in other research laboratories, use being made of reflecting galvanometers and the Dolezalek electrometer for d.c. measurements of surface and volume resistivity, and of the Schering bridge for the measurement of a.c. properties. Aquadag electrodes have proved very useful in facilitating tests. The experience gained over a number of years has led to the development of a simple and cheap type of conditioning tank in which materials are kept at controlled temperature and humidity prior to testing. Highly-insulated leads enable all measurements to be made with the samples *in situ*. A battery of these tanks is in use, and the results obtained under the controlled conditions form a basis for the Department's purchasing specifications.

Secondary Batteries.

The power supplies for the operation of automatic and manual telephone exchanges, and telephone repeater stations, etc., are obtained from secondary batteries, and the Post Office is the largest individual user of secondary batteries in the country. The individual capacity of the cells employed is from 8 ampere-hours to 10 000 ampere-hours, and the total capacity installed in this country for telephone purposes at the present time is 75 000 kWh. This plant has been laid down at a cost of £450 000.

The work in the Research Section in connection with secondary cells consists of the examination of new types of cells with a view to studying their economic application to telephone work, and experimental work on methods of maintenance and treatment of cells.

A small secondary-battery research laboratory adjoins the generator room. This is equipped with life-test units so arranged that cells can be charged at determined rates for specified periods and then discharged at definite rates and the cycle repeated. The cycles are automatically controlled by Venner time-switches, and recording voltmeters are used to obtain records.

Protection.

(i) *Electrolysis.*—Corrosion of Post Office underground plant is greatly increased by the electrolytic action of stray currents from tramway and other systems. In its 1921 report the American Committee on Electrolysis made the following statement: "The only accurate criterion of electrolytic damage is the intensity of current flow to earth from a pipe or cable. If an accurate measurement of this current flow from the pipe at any point could be made it would come nearer giving a true indication of electrolytic conditions than any other measurement." The development of an accurate method of measuring such currents locally has been one of the main objectives of the work done by the Research Section; and a set-up has been evolved which has proved effective for obtaining the necessary information so far as Post Office cables are concerned. The Post Office method has been recommended officially by the C.M.I. to other telephone administrations faced with similar conditions.

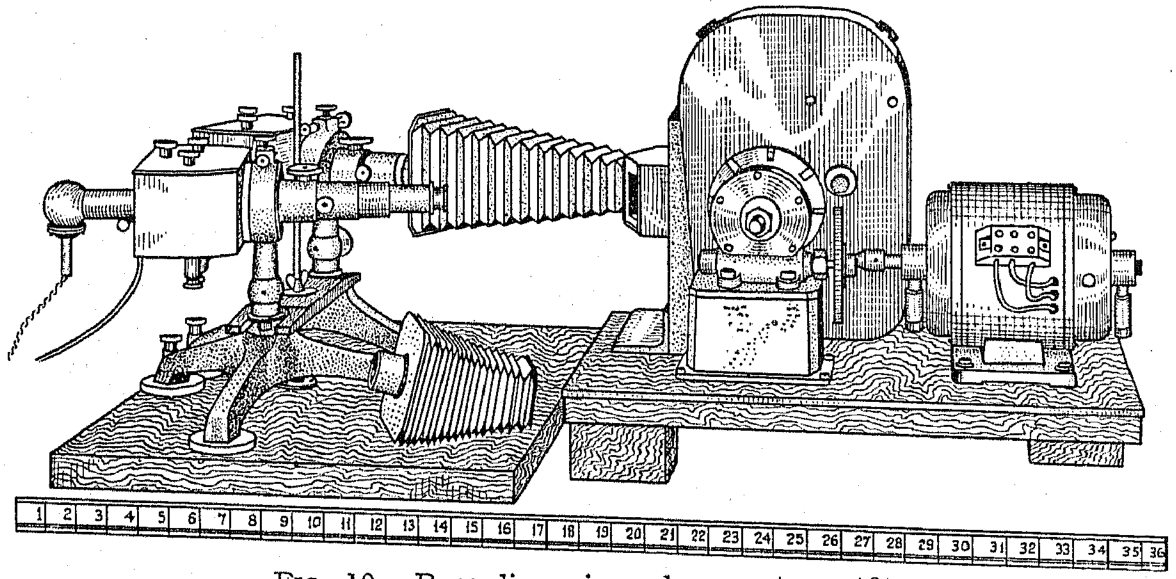

FIG. 10.—Recording-microgalvanometer outfit.

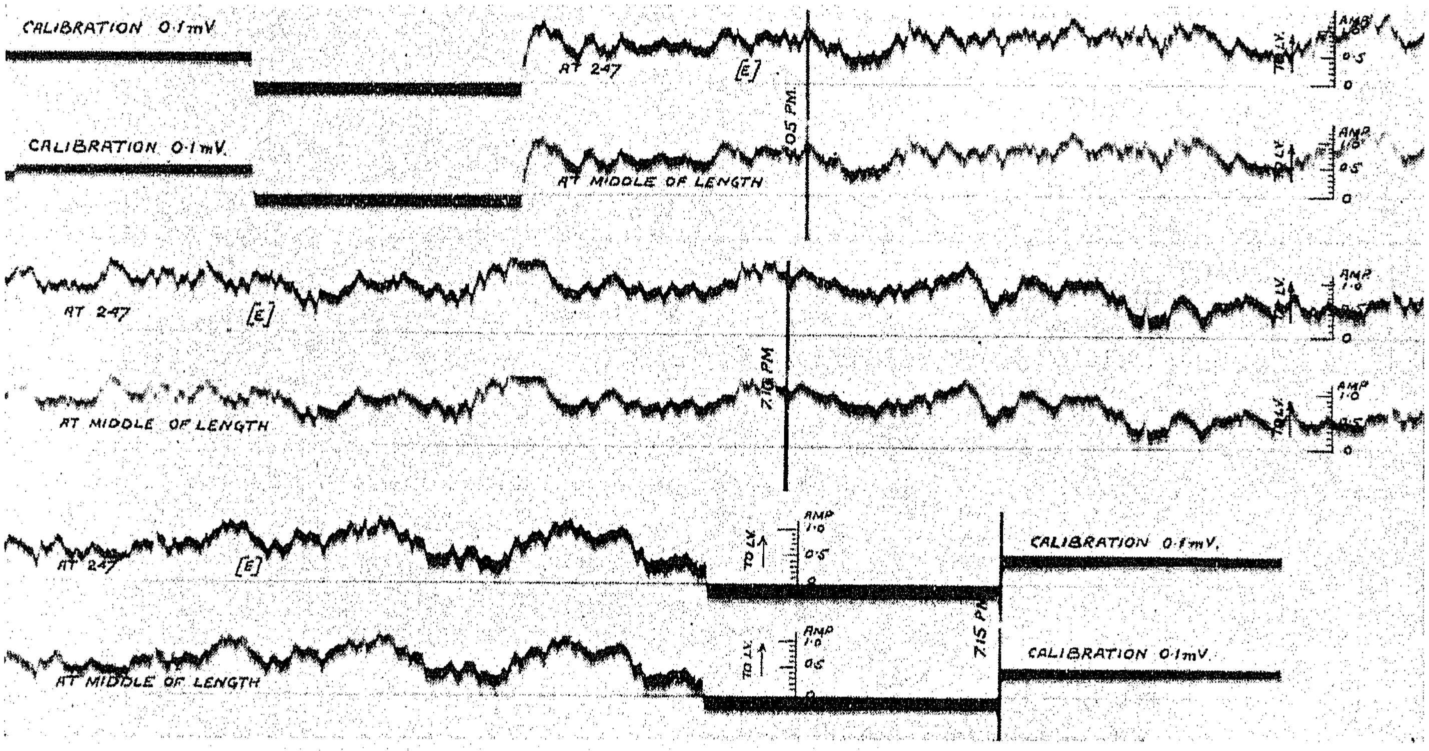

FIG. 11.—Recording-microgalvanometer record.

The apparatus is shown in Fig. 10 and consists of two micro-galvanometers recording on to a slowly moving photographic film. Each galvanometer is connected across a length of cable sheath of known resistance, and gives a continuous record of the current flowing in the sheath at the point of connection so as to measure simultaneously the sheath current at two adjacent manholes or footway boxes. Both currents are recorded on the same film, a typical record being shown in Fig. 11. These records, when measured up, give by difference the current flow to earth between the points in question.

(ii) *Telephone Interference.*—Inductive interference from power circuits is also investigated by this group. The effects of interference may be considered under the headings of *disturbance* and *danger*, the former being due to induction from the higher harmonics of the power system during normal working, and the latter to the dangerously high voltages at the fundamental frequency induced during fault conditions. With the construction of the Central Electricity Board's grid system the latter has become a problem of very considerable magnitude for the Post Office.

Field investigations are frequently carried out in co-operation with the technical staff of the Electrical Research Association. Such researches are planned and carried through under the aegis of the Telephone Interference Sub-Committee of the E.R.A., on which the Department is represented, together with such bodies as the C.E.B., the railway companies, etc. A noteworthy number of major investigations have been undertaken in this way during the past 3 years. These have already been described to the Institution during the present session in a paper coming jointly from the E.R.A. and the Post Office.*

Investigation of Telephone Instrument Protectors, etc.

An impulse generator on the lines of that installed at the National Physical Laboratory and giving a discharge of about 250 000 volts has recently been built and is proving of considerable use in testing lightning arrestors and investigating the effects of lightning discharges on communication systems and apparatus.

This generator consists of a 60 000-volt transformer, the output of which is rectified by a large thermionic diode valve. The rectified current charges five high-voltage micanite condensers in parallel and these, when fully charged, are connected in series by the discharge of individual spark-gaps to a main spark-gap. The energy of the discharge is approximately 60 watt-seconds, and as the discharge is of very short duration, probably of the order of a microsecond, the maximum intensity of the discharge is about 40 000 kW. We are much indebted to Dr. E. H. Rayner for valuable information in connection with the design of this generator.

Photo-electric Applications.

Various research groups have kept in close touch with developments in photo-electric cells and their practical application to such systems as picture telegraphy, etc. A certain number of special applications of photo-electric cells have been made recently, and it is proposed to refer briefly to one of these.

Chart Analyser.—In connection with the determination of the requisite number of automatic mechanisms to install in particular telephone exchanges, it is necessary that certain records of traffic operations should be taken. These are obtained in the form of a number of ink lines on charts 20 yards in length. The analysis of such a record takes a man about 2 days. A photo-electric analysing device has been designed and is now in operation which automatically carries out the analysis in 2 hours.

Light is reflected from the surface of the chart as it unrolls in the field of a microscope, and the illumination varies according to whether the reflection is from the ink line of the chart or from the surface of the paper where the ink line is deviated, and a photo-electric cell and valve-controlled relays are thus enabled to operate two metering devices, one of which records the number of deviations of the ink line and the other the total length of the deviations.

Oscillographs.

These instruments are of great importance for telecommunication research, and all groups make considerable use of them. Three types of electromagnetic and three types of cathode-ray oscillographs are in general use. At one time the groups developed their own oscillograms in individual dark-rooms, but this led to non-uniformity in results. In order to get over this difficulty the photographic sub-group now undertakes an oscillogram service. Any group after taking an oscillogram sends the undeveloped film or paper to a central dark-room where the most suitable developing and, if necessary, intensifying technique is immediately applied.

This service has resulted in the production of high-grade and uniform oscillograms.

B. LINES TRANSMISSION GROUP.

This group is concerned with telephone transmission over long lines and therefore deals mainly with repeater and carrier systems. This includes the development of apparatus for audio- and carrier-frequency measurements, design and construction of wave filters, and the development of the subsidiary apparatus, such as echo-suppressors, associated with long lines. The group also undertakes the testing of new types of thermionic valves.

It is not proposed to enter here into details of the work of this group, as its activities will probably form the subject of a special paper at a future date. As an example, however, of the type of problem met with on long telephone circuits, reference will be made to the echo-suppressor.

A talker on a long, loaded, telephone line may hear an echo, due to reflection from the far end, of sufficient volume and time-delay to be very disconcerting. The problem of echo was tackled as soon as it arose, and two Post Office Research engineers invented an echo-suppressor in which, by the operation of valves only, speech in one direction cuts down the amplification in the other, so that an echo is suppressed, or at least reduced to harmless dimensions, before it reaches the talker.*

In America echo-suppressors using valve-operated magnetic relays had been produced somewhat earlier, and in Germany a valve-type suppressor was invented just after the Post Office suppressor, but quite independently.

The principle of using valves exclusively in echo-suppressors and other voice-operated devices has proved to have decided advantages. Valve-type echo-suppressors are now used throughout Europe.

Recently it has been discovered that cuprous-oxide rectifiers can be used in place of valves as controlled variable impedances, and a valveless echo-suppressor has been designed by Dr. Ryall (of the lines transmission group) and proved entirely satisfactory. The repeater valves are made to act as d.c. amplifiers of rectified speech currents, and the direct current thus produced is used to control the impedance of series and shunt rectifiers arranged to form a variable attenuator. Fig. 12 shows the circuit.

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* W. G. RADLEY, B.Sc.(Eng.), and S. WHITEHEAD, M.A.: "Recent Investigations on Telephone Interference," *Journal I.E.E.*, 1934, vol. 74, p. 201.

* C. ROBINSON and R. M. CHAMNEY: "Recent Research Work on Telephone Repeaters," Institution of Post Office Electrical Engineers, Paper No. 99, 1924.

The new suppressor is considerably cheaper in first cost and maintenance than the valve-type suppressor.

In addition to their main use, echo-suppressors enable zero-loss circuits to be maintained without difficulty. If the overall equivalent happens to fall below zero the circuit will become unstable in certain conditions, but when an oscillation builds up to a very small value it is cut off by the suppressor, starts again, and so on. It can never reach sufficient magnitude to disturb other circuits.

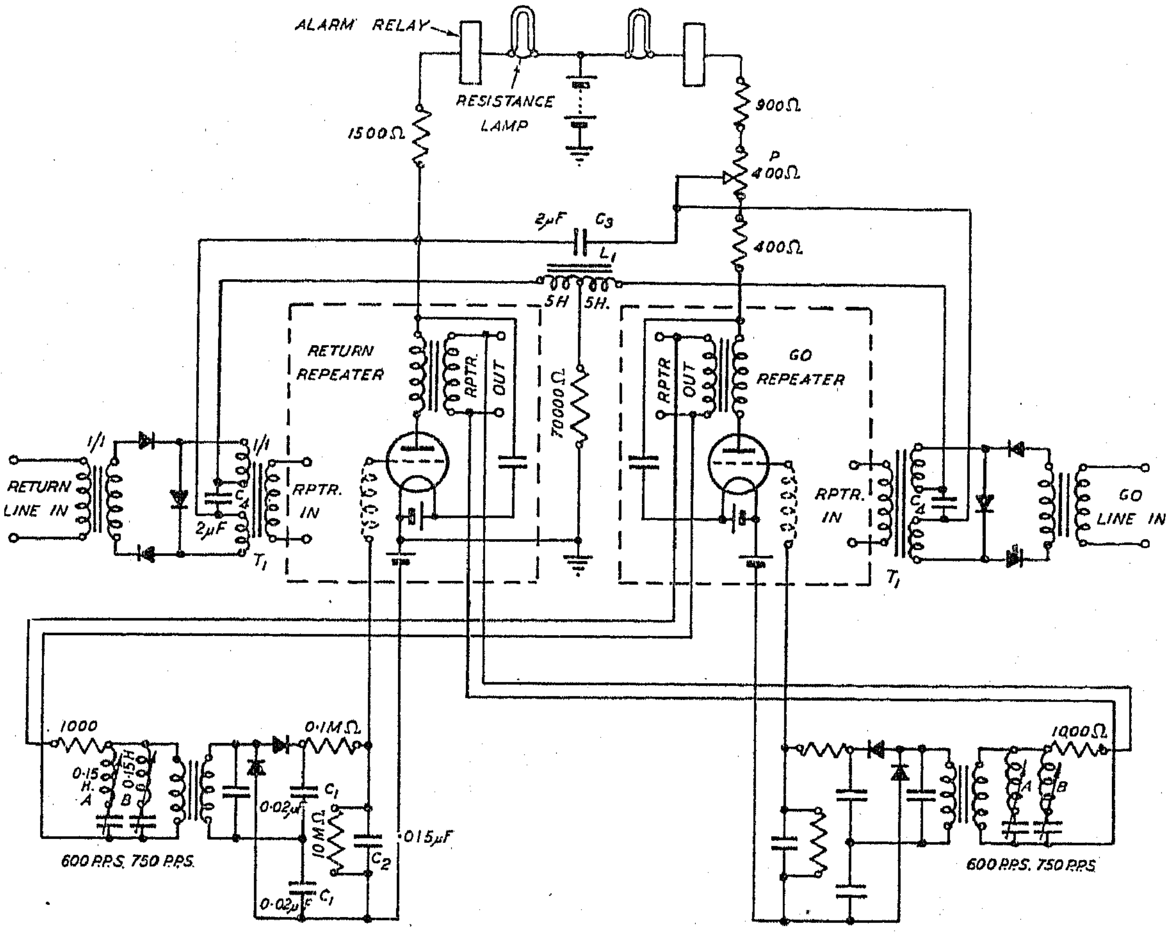

Fig. 12.—Diagram of valveless echo-suppressor connected to 4-wire repeater.

Heterodyne Oscillator.

The oscillator as a source of alternating current has become an important factor in telecommunication research and measurement.

The heterodyne type of oscillator was originally a product of Post Office research. So far as the author is aware, the first account published was in the *Journal* in 1926.* Since that date it has become an important tool in the hands of the research engineer and is in universal use. One of its main drawbacks, however, has been its instability. A precision heterodyne oscillator has been recently developed by the lines transmission group, in collaboration with a well-known firm of scientific-instrument makers whose precision condensers and inductances contributed very considerably to the accuracy and stability of the oscillator. It has the following performance:—

(1) A frequency drift of less than 1 cycle per sec. per day.
(2) A calibration accuracy of ± 0·2 per cent between 40 and 10 000 cycles per sec.
(3) A constant output into 600 ohms between 20 and 10 000 cycles per sec., with a total variation of less than 0·1 decibel.
(4) A harmonic content of less than 1 per cent for outputs of 100 mW at all frequencies over 40 cycles per sec., and less than 0·33 per cent at all frequencies over 300 cycles per sec. for outputs of 50 mW. With an output of 200 mW the harmonic content is less than 3 per cent for all frequencies above 20 cycles per sec.

An interesting device for reducing the harmonic content of the output signal consists of a cuprous-oxide rectifier in parallel with a resistance, the combination being in series with the output of an amplifying valve. This provides a compensating device acting in the opposite direction to the curvature of the valve characteristic, and actually reduces even harmonics by about 10 decibels.

C. Telephone-Apparatus Transmission Group.

This large group is divided into two sub-groups, each in charge of an executive engineer. One sub-group deals with the electrical and part of the electro-acoustical side of telephone-apparatus transmission research and carries out all the subjective testing work, i.e. voice-ear measurements of volume, articulation, etc., whilst the other sub-group deals with acoustical and also basic electro-acoustical work. Fig. 13 gives details of the subdivision.

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* B. S. Cohen, A. J. Aldridge, and W. West: *Journal I.E.E.*, 1926, vol. 64, p. 1023.

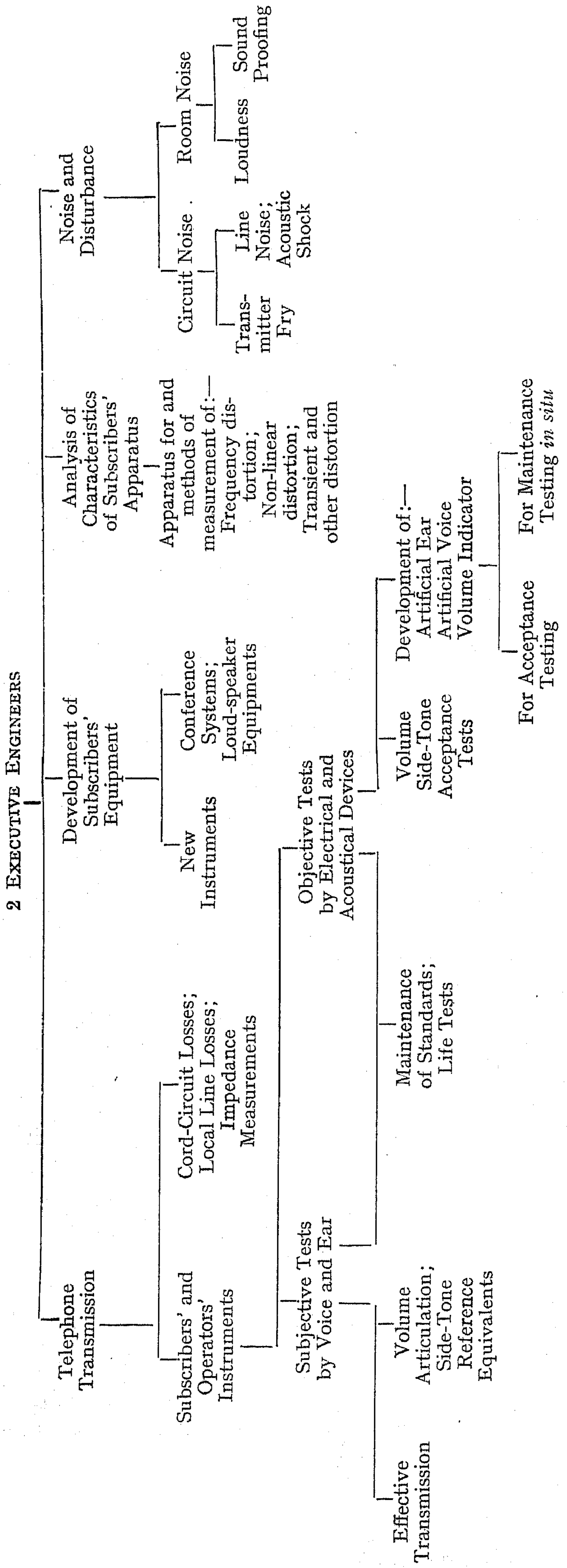
2 Executive Engineers
Telephone Transmission
Development of Subscribers' Equipment
Analysis of Characteristics of Subscribers' Apparatus
Noise and Disturbance
Subscribers' and Operators' Instruments
Cord-Circuit Losses; Local Line Losses; Impedance Measurements
New Instruments
Conference Systems; Loud-speaker Equipments
Apparatus for and methods of measurement of:— Frequency distortion; Non-linear distortion; Transient and other distortion
Circuit Noise
Room Noise
Trans-mitter Fry
Line Noise; Acoustic Shock
Loudness
Sound Proofing
Subjective Tests by Voice and Ear
Objective Tests by Electrical and Acoustical Devices
Effective Transmission
Volume Articulation; Side-Tone Reference Equivalents
Maintenance of Standards; Life Tests
Volume Side-Tone Acceptance Tests
Development of:— Artificial Ear Artificial Voice Volume Indicator
For Acceptance Testing
For Maintenance Testing *in situ*

FIG. 13.—Telephone-Apparatus Transmission and Acoustics Group.

The whole of the accommodation on the first floor (west wing), in addition to three rooms on the second floor (west wing), is devoted to telephone-apparatus transmission research (see Figs. 4 and 5).

The telephone reference standard laboratory on the first floor has a smaller room leading out from it for the listening end. There are also a series of five rooms, A to E, which are used for voice-ear transmission measurements. Each of these rooms has direct access to smaller rooms which are used as silence rooms.

Adjoining C is a screened laboratory containing the apparatus necessary for carrying out life tests on transmitters and receivers.

At the western end of the corridor are two larger laboratories, one of which is devoted to investigations into methods of testing transmitters and receivers by means other than use of the actual voice and ear, and the other, which is electrostatically screened, is used for general investigations into apparatus transmission, including various a.c. measurements and oscillographic work.

Provision is made in all the voice-ear measurement rooms for the introduction of varying amounts of controlled room noise produced by gramophone records and loud-speakers. The additional accommodation for this group on the second floor (see Fig. 5) consists of three rooms, one of which is devoted to individual research. The other two are telephone demonstration rooms, which merit more detailed description.

Telephone Demonstration Rooms.

These two rooms have been so arranged that typical telephone connections for demonstration purposes can be set up between them. All the various types of telephone instruments and circuits are installed in each room, providing normal or diminished side-tone, common-battery and local-battery conditions, and so forth. These instruments can be interconnected through local lines of various types and lengths, and trunk lines with a range of from zero to 40 decibels of attenuation, either distortionless or equivalent to ordinary unloaded cable. Filters are also provided to give four different cut-off frequencies representing four types of loaded lines. Line noise, consisting of induction from a power circuit, can be applied in 4 steps giving a range of from 0·15 to 2·7 mV across the telephone receiver. In a similar way the scratching noise sometimes occurring in telephone circuits can be applied in 4 steps with a range of 0·15 to 2·7 mV.

A gramophone, provided with a typical office noise record, supplies room noise to loud-speakers situated in each of the rooms, and this can be controlled independently in each of the rooms at noise-levels of zero, 40, 55, 65, or 75 decibels.

These various components and impairments of a telephone connection can be varied by means of keys placed in a control case standing on the telephone tables, and the rooms have proved of great use in studying and demonstrating the overall effects of different impairments on telephone transmission. It is of interest to mention that one of the rooms has controllable acoustic absorption obtained by opening and closing folding wall panels lined with absorbent material.

An extensive series of tests is in hand to correlate the various transmission impairments, and for this purpose pairs of observers, both male and female, taken at random from the staff, make calls of a few minutes' duration during which conversations of a social, business, and technical nature are carried on in as natural a manner as possible. The conditions are varied at intervals, and the number of repetitions due to unintelligibility are recorded by a separate observer. Rooms equipped in a similar manner have been in use for some years by the American Telephone and Telegraph Co., who have found them of great value.

Life-Test Apparatus.

This apparatus is intended for making life tests on telephone transmitters under conditions approaching as nearly as possible those under which the transmitters are normally used in practice.

Provision is made for testing 30 microtelephones and 30 pedestal instruments simultaneously. The microtelephones are lifted from their cradles for a period of 1½ minutes every 3 minutes, and are "spoken to" by receivers supplied with energy from a sound film for periods of about 4 seconds, withsilent periods of the same duration.

The pedestal instruments have their receivers raised from the switch-hooks for similar periods, and the transmitters are "spoken to" in the same fashion.

Instruments are connected in pairs by local lines (zero or 300 ohms) and standard cord circuits.

Jacks are provided so that each transmitter may be tested for resistance either during operation of the apparatus or separately.

Jacks are also associated with the cord circuits so that the output of each transmitter may be measured on an a.c. voltmeter.

The measuring instruments are mounted on a central control and testing panel.

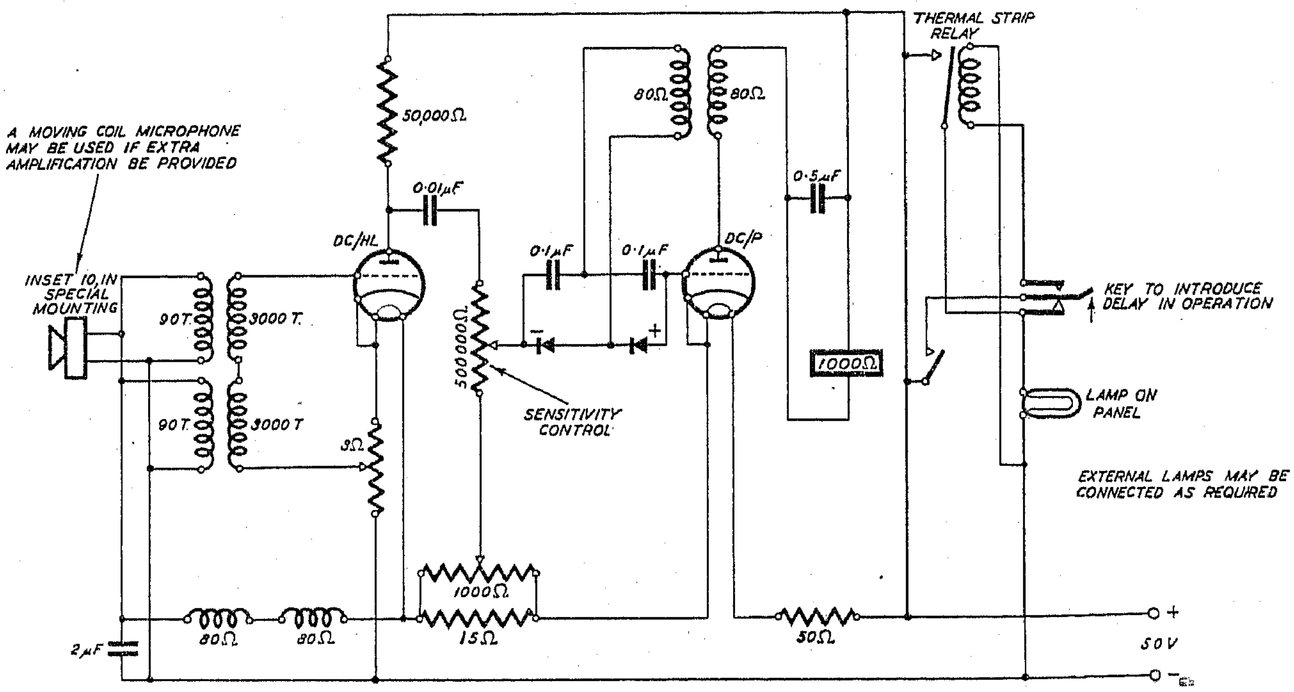
THERMAL STRIP RELAY
50,000Ω
80Ω
80Ω
A MOVING COIL MICROPHONE MAY BE USED IF EXTRA AMPLIFICATION BE PROVIDED
0·01μF
0·5μF
DC/HL
0·1μF
0·1μF
DC/P
INSET 10, IN SPECIAL MOUNTING
90T.
3000 T.
500000Ω
KEY TO INTRODUCE DELAY IN OPERATION
1000Ω
90T.
3000 T
3Ω
SENSITIVITY CONTROL
LAMP ON PANEL
EXTERNAL LAMPS MAY BE CONNECTED AS REQUIRED
1000Ω
2μF
80Ω
80Ω
15Ω
50Ω
+
50V
−

FIG. 14.—Sound-level indicator operating from 50-volt supply.

Acoustic Laboratory.

The acoustic laboratory is equipped primarily for basic objective measurements of telephone transmitters, receivers, and loud-speakers. The fundamental measurements developed here, primarily depend on the use of the Rayleigh disc; they have been described in papers published in the *Journal*.*

Fundamental Calibrations.—In the first place a high-quality microphone, generally electrostatic, is calibrated by means of a Rayleigh disc. Two methods are available, for one of which a spherical sound-wave is generated in a wooden box, 4 ft. cube, lined, to minimize reflections, with cotton wool and cotton waste; the sound wave actuates both the Rayleigh disc and the microphone. The other method makes use of a closed tube with the Rayleigh disc suspended at the centre, a source of sound being mounted at one end and the microphone at the other end.

The fact that different results are obtained from the calibration of a microphone by these two methods has been made use of for investigating the effects on the sound field of the presence of the microphone itself; in the spherical-wave method it is the free-air sound pressure that is measured, while in the tube test it is the actual pressure exerted on the diaphragm.†

Telephone Transmitters.—A calibrated microphone is used to measure the sound pressure in a sound field to be employed for testing the transmitters used in commercial telephony. Sound fields of strong intensity are produced by a loud-speaker unit operating into a 15-ft. straight exponential horn with a flare, nearly 4 ft. in diameter, terminating in a non-reflecting cabinet in which the measurements are made.

Loud-Speakers.—A non-reflecting room, with linings of cotton wool exceeding 1 ft. in thickness, permits measurements of sound pressures from loud-speakers, working under the equivalent of "open air" conditions, at distances up to about 10 ft. As might be expected, this room has an exceptionally—in fact totally—silent background of noise. Consequently it is useful also for special listening tests for which a completely silent background is essential; for example, tests of the threshold of hearing.

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* B. S. COHEN, A. J. ALDRIDGE, and W. WEST: *Journal I.E.E.*, 1926, vol. 64, p. 1023; also E. J. BARNES and W. WEST, *ibid.*, 1932, vol. 71, p. 605.

† W. WEST: *Journal I.E.E.*, 1929, vol. 67, p. 1137; and 1930, vol. 68, p. 441.

Telephone Receivers.—In accordance with the important principle of carrying out tests, as far as possible, under working conditions, receivers are tested on an artificial ear. This apparatus simulates the acoustical load of a real ear when the receiver is firmly held thereto, and measures the sound generated by the receiver.[*]

Frequency-Characteristic Measurements.—Associated with a heterodyne oscillator is a variable condenser to the shaft of which is connected a drum carrying a sheet of paper. Adjacent to this condenser, a straight-line-law amplifier-rectifier supplies the rectified current to be recorded, to a galvanometer whose mirror reflects a beam of light on to the paper. As the drum is rotated, i.e. as the frequency is varied, the spot of light on the paper maps out the frequency characteristic.[†]

Measurement of Room Noise.—Portable apparatus for subjective measurement of room noise is used. This consists of a valve oscillator, attenuator, and receiver. The tone (1 000 cycles per sec.) from the receiver is adjustable to balance the magnitude of sensation with that of the noise to be measured, and the attenuator reads the level, in decibels, above the normal threshold of hearing. The readings are related to sound pressures by measurements on the artificial ear.

Purely objective noise-indicating apparatus has also been designed, not primarily for measurement purposes, but to aid supervision in manual-exchange switchrooms and similar situations. A microphone and amplifier are terminated by a relay, which lights a lamp to inform the supervisor that the room noise has exceeded a certain predetermined level, i.e. that the general level of speech by the operators is unnecessarily high.

This sound-volume indicating apparatus has another useful application. It can be set up to indicate that a speaker taking part in a discussion is speaking loudly enough to be readily heard by all his auditors. The circuit of the sound-volume indicator is shown in Fig. 14.

Acoustical measurements have also to be applied to the problem of obtaining a sufficient degree of secrecy in telephone cabinets and kiosks, and portable apparatus is used for measuring the attenuation of sound effected by different cabinets.

D. Cable Research Group.

This group deals with the research problems which arise in connection with the design and testing of land and sea cables.

In addition the group carries out acceptance tests of repeatered sections of trunk lines and all submarine cables, and also deals with the location of faults in the latter. The group collaborates with the materials group in research on the materials used in the construction of cables, and carries out investigations on cable dielectric materials at audio and carrier frequencies. It also investigates methods of measuring cross-talk by subjective (aural) means and by objective devices such as amplifier-rectifier voltmeters. The training of district staff in the precision a.c. measurements work involved in balancing and testing land cables is also carried out by this group.

Electrode Testers.

Considerable work has been done during the last 2 years in developing a new method of locating a faulty cable and in finding the position of the earth fault thereon. The method is different from existing fault-location tests in that it is used from the cable ship itself, an earthed a.c. supply of 17 cycles per sec. being fed into the faulty core from one end of the cable. Two electrodes are towed from the ship, the distance between them being approximately 20 yards. Each is connected by an insulated lead to a powerful tuned amplifier-rectifier on board. The leakage current returning from the fault via the sea itself produces a voltage gradient in the water between the fault and the 17-cycle machine earth. This voltage gradient is of the order of 1 microvolt per yard. The amplifier-rectifier, as at present developed, will give sufficient output from 10 microvolts of input to cause a deflection of 100° on a unipivot galvanometer. It will be seen, therefore, that if the electrodes are towed in such a way that they lie in the direction of the voltage gradient, very definite indications will be given on the galvanometer. These indications are a maximum when the electrodes are over and parallel to the cable and between the fault and the 17-cycle machine. Beyond the fault the indications rapidly fall off to zero.

This method has been successfully tried at various stages of its development, the latest case being a 100-ohm earth fault in 15 fathoms at 65 nauts from Borkum on the Bacton–Borkum No. 1 cable. The cable was easily found and traced, and the fault position as located by the electrodes was within $\frac{1}{4}$ naut of the actual fault, which was subsequently cut out. In the case of old cables which have been "sanded" and are difficult to hook, much grappling time is saved if the cable location can actually be determined instead of its being necessary to place reliance upon the accuracy of its charted position, and, further, the use of the electrodes carefully towed abeam while grappling enables waste time to be reduced to a minimum as a clear indication is given each time the electrodes pass over the cable.

When arrangements are made whereby 17-cycle supply can be switched on to any submarine cable on receipt of wireless instructions from a repair ship, the new method will undoubtedly develop into one of the most useful tests available in connection with submarine repair operations. On gutta-percha cables the useful reliable range of the apparatus now available is estimated as 150 nauts from either end.

Experience of the method at present with lead-covered cable is limited to one fault at 4 miles in 25 fathoms, but the results were so convincing that, combined with the above experience on gutta-percha cable, there is no hesitation in forecasting that the range for paper-core cables, reduced owing to the presence of a lead sheath, will be of the order of 15 miles from either end.

E. Telegraph Research Group.

The laboratories of this group are on the second-floor west wing of the main building.

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[*] W. West: *Post Office Electrical Engineers' Journal*, 1928–29, vol. 21, p. 293; and 1929–30, vol. 22, p. 260.

[†] B. S. Cohen, A. J. Aldridge, and W. West: *Journal I.E.E.*, 1926, vol. 64, p. 1031.

Although the impression often appears to have been held that telegraphy, the oldest branch of electrical communications, has lagged behind the other branches in matters of development, none the less, during recent years, the whole character of telegraphy has changed and is still changing.

The most important development has been the introduction of the teleprinter, which has almost entirely replaced all other systems of telegraphy in this country. The next most important development is the widespread introduction of multi-channel voice-frequency systems with considerable economies of line plant. Further important developments are the introduction of Telex, which is a facility enabling subscribers to teleprint over the telephone network, and the extension of private-wire facilities by the use of telephone by-product circuits. The extension of teleprinter working on an international basis will no doubt follow in the near future. However, there are certain difficulties to be overcome before this can be accomplished, particularly with regard to the use of different keyboards, alphabets, and transmission speeds, by the various administrations. In the introduction of the foregoing innovations the research organization of the British Post Office has played an active part.

Important work recently carried out by the telegraph research group includes the design of a distortion tester particularly applicable to the teleprinter.[*] Considerable work has also been done on telegraph-circuit loading.

On a long double-phantom experimental circuit carried on telephone phantoms between London and Glasgow, loading coils were connected into the double-phantom link at the telephone repeater stations, as these were the only points at which the circuit could be conveniently broken.

The value of inductance of the loading coils was determined from steady-state considerations, the aim being to secure minimum distortion over the working range of frequencies (0–25 cycles per sec.), due account being taken of the unequal distances between the repeater stations. Although the work was not carried to its final conclusion, very definite improvements were obtained and distortion was reduced from a value which made working impossible without repeaters to one which gave a fair margin over long periods.

Some interesting results have also been secured using a magnetic shunt at the sending end. This method of reducing distortion is useful in that it can be applied to a differential duplex circuit and has been used with considerable advantage in the case of duplex sub-audio circuits.

Another development of interest has been the design of a regenerative telegraph repeater which not only repeats the telegraph signal at suitable amplitude but corrects the distortion of the received signal elements.[†]

F. Signalling Apparatus and Circuits Group.

This group deals mainly with research problems arising in connection with the design and maintenance of telephone exchange equipment. The advent of automatic telephony and the extension of the trunk services have called for considerable important investigation work for the purpose of providing new facilities and speeding up the establishment of connections. This entails the devising and proving-in of new devices and apparatus for exchange equipment. Also much work is undertaken to provide means for improving the standard of maintenance and reducing the operating costs of telephone exchange plant.

Two-Frequency Signalling System.

As an example of the type of research covered by the telephone-exchange signalling group, brief reference will be made to recent developments in voice-frequency signalling methods. An important example is the two-frequency system of signalling which, whilst of universal application, is of special importance for the "on-demand" trunk service. This system gives the same facilities of lamp signalling between trunk exchanges as is now given by means of direct currents for working via junctions between exchanges in the same area. The voice-frequency currents can be transmitted over any efficient speech channel and can control lamp signals at the exchanges. Special valve circuits have been devised to provide means of operating relays by voice-frequency currents and at the same time to be immune from operation by speech currents.

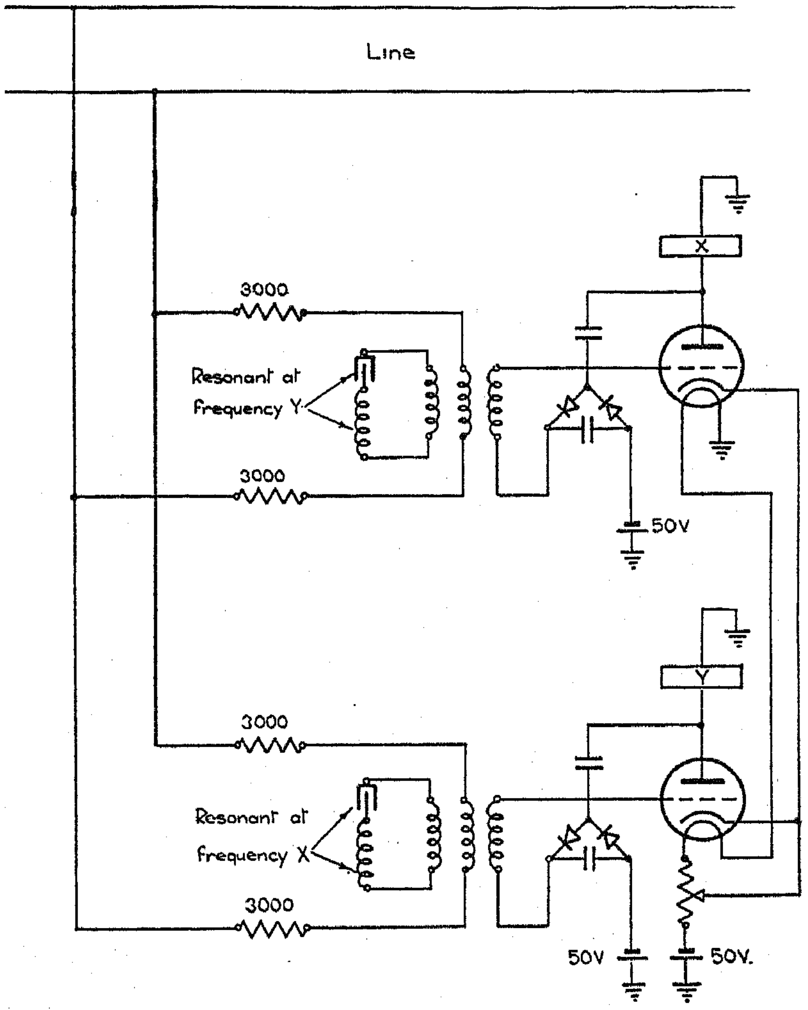

FIG. 15.—Two-frequency voice-frequency signalling circuit.]

The principles on which this system operates may be briefly stated as follows. The trunk line is equipped with two units of apparatus at each end, one being a relay set and the other a voice-frequency receiver. The circuit of the latter is given in Fig. 15, which shows two relays X and Y controlled by voice-frequency currents.

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[*] E. H. JOLLEY: "Determining the Transmission Efficiency of Telegraph Circuits," *Post Office Electrical Engineers' Journal*, 1933–4, vol. 26, p. 1.

[†] E. H. JOLLEY and J. A. S. MARTIN: "Regenerative Repeater for Teleprinter Systems," *ibid.*, 1933–4, vol. 26, p. 171.

Relay X is prevented from operating at 600 cycles per sec. by a resonant circuit, but readily operates at all other frequencies or with speech. Similarly relay Y is prevented from operating at 750 cycles per sec. but readily operates at any other frequency or with speech. The circuits which are operated by relays X and Y are so arranged that the signalling facilities are given by either X or Y operating at separate times. Speech or frequencies other than 600 and 750 cycles per sec. will operate both X and Y but this condition is arranged to be inoperative as regards the remainder of the equipment. The valves operate on the principle of rectified reaction described in the following paragraphs.

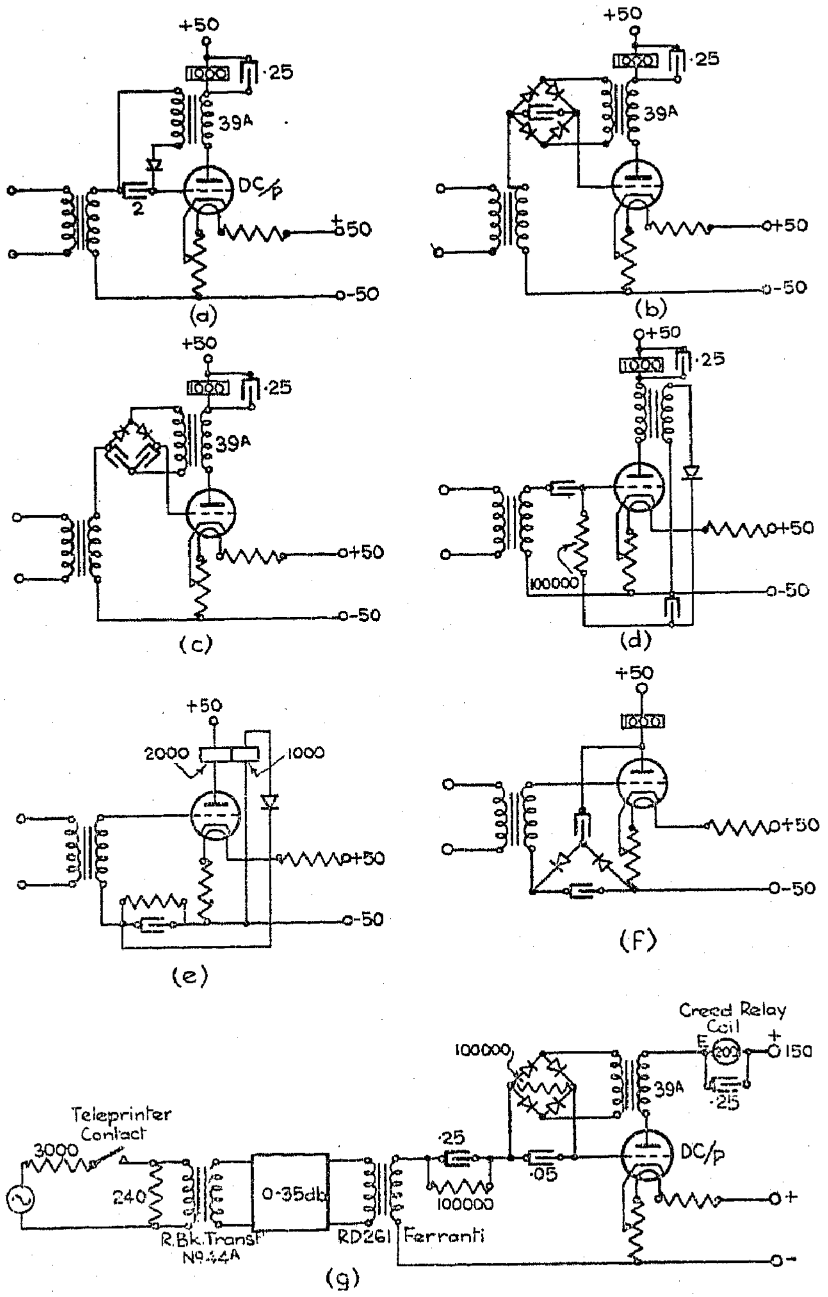

FIG. 16.—Valve relay circuits using rectified reaction.

Rectified Reaction.

Rectified reaction* is an arrangement whereby a much improved sensitivity and speed of working is obtained for the operation of a relay in the anode circuit of a valve used as a rectifier for alternating current. The method is to feed back a portion of the anode current and to rectify this portion and cause it to charge a condenser in such a way that the grid of the valve, normally negatively biased, becomes rapidly positive, with consequent rapid increase in anode current.

Fig. 16 shows various circuit arrangements which have been used. In one of the circuits, feed-back is via a transformer and in another via a condenser, rectification of the feed-back being obtained by means of a metal rectifier.

Fig. 17 shows how better results, as regards both sensitivity and sharpness of action, are obtained with rectified reaction as compared with anode-bend rectification.

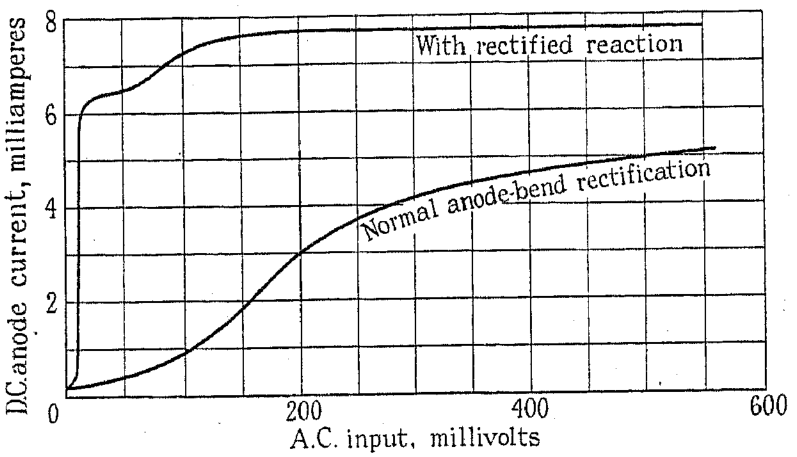

FIG. 17.—Curves showing relative sensitivity of valve relay circuits using rectified reaction and anode-bend rectification.

Relay Contacts.

The signalling group, in collaboration with the materials group, investigates the behaviour and life of various designs of contacts.

Relay contacts may be divided roughly into two categories, heavy-duty and light-duty types. The heavy-duty types include impulsing contacts to energize the magnets of Strowger selectors and interruptor contacts of driving magnets of uniselectors, and are fitted with a spark-quench. The light-duty types control relay circuits and in so doing may or may not break a current.

In the case of impulsing contacts, especially those used in director apparatus, the wear is considerable, as a pair of contacts have to perform millions of operations annually. A considerable amount of work has been done to determine the effect on contact wear of such factors as composition and physical condition of the contact material, contact bounce, relay adjustment, and most suitable spark-quench.

The apparatus used for these contact life-tests is constructed to test 8 groups of 6 contact pairs. The contacts are operated in a vertical magnet circuit of a Strowger switch, and a machine interruptor supplies Strowger impulses in 7 trains of 10 with a 1-second pause between each train and a 14-second pause between each series of trains. This ensures results comparable with those obtained in practice, and avoids overheating of the magnets.

The approximate heavy-duty life in millions of operations of a few of the best materials as determined by this apparatus is:—

Platinum-iridium alloy (10 per cent Ir)	100 millions
Platinum	40 millions
Palladium	21 millions
Silver	9 millions

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* L. H. HARRIS: *Post Office Electrical Engineers' Journal*, 1932, vol. 25, p. 190.

The life of these contacts naturally depends to a great extent on the melting point of the material. Tungsten on this account gives a much longer life than any of the foregoing but is prohibited on account of the formation of high-resistance oxides.

Twin contacts give twice the life of single contacts of the same dimensions.

The wear on light-duty contacts is negligible, but the fault liability due to dust is the important factor in their maintenance. Lengthy investigations have been made into the effects on fault liability of contact pressure, spring travel, methods of mounting the relays, and the cleaning of the contacts. It has been found that fault liability is reduced by (1) fitting dust-tight covers on the relays; (2) mounting the relays with springs in the vertical plane; (3) higher contact pressure; (4) small spring travel; (5) twin contacts; and (6) using silver in preference to platinum or platinum-gold-silver alloy.

Schedule giving average number of calls during a year for various types of apparatus.

No.	Apparatus	Average calls during a year
1	Subscribers' uniselector (ordinary) ..	2 700
2	Subscribers' uniselector (P.B.X.) ..	38 000
3	1st code selector	28 500
4	" A " digit selector finder	33 500
5	" A " digit selector	220 000
6	Director	175 000
7	Coder	220 000
8	Code call indicator position	600 000
9	Sender finder (4-digit)	160 000
10	Sender (4-digit)	350 000
11	Key-sender " B " position (4-digit) ..	650 000
12	Sender finder (7-digit)	175 000
13	Sender (7-digit)	300 000
14	Key-sender " B " position (7-digit) ..	700 000

For a number of years platinum-gold-silver or gold-silver alloys were extensively used for light-duty contacts. Post Office researches now indicate that silver, besides being much cheaper, has very definite advantages, and it is being adopted by the Department.

Durability Testing.

The durability testing of telephone equipment is rather a noisy proceeding, and is carried on in a laboratory separated from the main buildings and with its office accommodation partially sound-insulated.

It will be appreciated that durability testing has to be made intensively, and usually 30 years' normal life has to be covered in a few weeks. In order to compute the duration of the testing period necessary to cover a given normal life in practice, the information given in the accompanying schedule is utilized. This has been prepared from traffic statistics. Before the test on a given piece of apparatus is commenced a testing circuit is designed which will cause this apparatus to perform the function for which it has been designed, and also to detect a faulty operation and operate an alarm circuit in case of a fault. The apparatus is then given its correct adjustment and lubrication and set to operate either continuously or intermittently for an allotted number of times. The test is then stopped and the apparatus examined for adjustment, wear, etc. These examinations are made at definite intervals during the life test and also serve as rest periods for the apparatus under test, to ensure that no undue fatigue is produced due to speeding-up the test in comparison with practical conditions. Testing is continuous and usually proceeds day and night and also during week-ends. The testing circuits are always designed to stop the test on the occurrence of a fault, and to signal it by lamps and also by a loud-sounding buzzer.

A few typical examples of the type of test in progress are:—

Life test of complete switch mechanisms, Strowger and uniselector types.
Life tests of dials.
Effectiveness of lubricants for automatic switch mechanism.
Relative wear of various materials for use in wipers and bank contacts, etc., of selector mechanisms.
Wear of relays and meters.
Life test of heavy-duty contacts.

H. EDITORIAL, LIBRARY, AND PATENTS GROUP.

This group takes charge of the library (see Fig. 5), which now forms the central library for the Engineering Department, and contains at present about 4 000 books and other publications. A series of technical abstracts covering items of special interest to communications engineering, apart from those already abstracted in such publications as *Science Abstracts* and the radio abstracts in *Experimental Wireless*, is kept and circulated to those interested. A weekly circular is issued drawing attention to items of special communications interest, giving particulars of the additions to the library and referring to forthcoming scientific and technical meetings of interest to the Engineering Department. This group is also concerned with the editing and co-ordinating of research reports.

Associated with the group is the patents organization.

CONCLUSION.

An attempt has been made within the brief limits of this paper to survey the activities of the Post Office in the field of telecommunication research and to describe the Dollis Hill Research Station, its equipment, and its organization. Some particulars of the types of investigations carried out by the various research groups have been included.

The art of telecommunication has developed in range and complexity to an astonishing extent since 1918, and telecommunication research requires a considerable number of specialists, on whose capabilities and enthusiasm depend its successful pursuit.

The author wishes to express his indebtedness to the research specialists, past and present, who have made it possible for him to record this description of Post Office research activities.

Discussion before The Institution, 1st February, 1934.

Mr. C. C. Paterson: The Dollis Hill Research Station is designed to serve an organization with a capital of over £100 000 000, and, magnificent as its laboratories are, they are none too lavish for such an enormous industrial undertaking. I should like to ask the author what accommodation he has allowed in the laboratories for discarded apparatus which has to be kept even though it will not be used at all often. The accommodation for which I originally allowed at Wembley, and which is still not enough, was 12 per cent of the whole floor area. The author briefly refers to the valuable discovery, made by his department, that certain oils could be used for covering up the acid surfaces of secondary batteries. We have benefited enormously by that, for it has given us batteries which work well for many years without giving rise to acid fumes. I do not quite know why the Post Office want to do further research on the matter, because in the form in which they first gave it to us the discovery seemed almost perfect. With regard to arrangements for locating members of the staff of the laboratories, the author mentions that at Dollis Hill a system of signal lights is found sufficient. We are now installing about 40 loudspeakers in our laboratories for this purpose. The author's system of locating the local small-job workshops all in one building is interesting. At Wembley we have found that the best solution is to have small local workshops alongside most of the laboratories, so that a research worker has not to go far if he wants to do a mechanical job. On page 137 the author gives some details of the members of the staff, but he does not state the average number of non-experimental staff employed per experimental worker. In a number of laboratories this seems to be about 2, but in many cases it is as low as 1·5. It is my experience that an engineering or physical laboratory cannot be efficiently run unless this number exceeds 1·5. With regard to stores and storekeeping, we have an identical system to that described in the paper, and it is found to be an ideal arrangement. Turning to the X-ray spectrographic service, probably in 30 per cent of the problems we have to solve we make use of X-ray analysis. The author mentions an interesting and attractive routine system of obtaining quantitative results from X-ray analysis of materials. In order to achieve this in a preliminary quantitative analysis we have developed what we call an " R.U. powder," which contains traces of the majority of the elements in the correct proportion to reveal their ultimate spectral lines. We have proved that by taking a comparative spectrum of this in juxtaposition to the unknown it is possible very rapidly to read off the quantitives of the additives present in the spectrum. I should like to mention one general consideration with which I am not sure the author will agree. The Post Office has a monopoly of inside information with regard to the operation of telephones. Information with regard to all future technical demands is what the manufacturing industry needs in order to compete in the world markets. The technical staff of the Post Office has always been mindful of this, and in their technical publications and their discussions with manufacturers they have always adopted an extremely helpful attitude; but the danger, and, indeed, the very definite handicap, is always there. The Post Office is, from the nature of its constitution, uninterested in business contracts and foreign markets, and it is inevitably divorced from the rest of the industry by the age-long tradition which adorns every organization which is under Government control, or which has been given a monopoly. It is only the goodwill of the technical management that maintains a liaison between the administration and the industry. We hope that the policy of the Post Office will always be to avoid tendencies which locate the technical brain of this great industry of electrical communications solely or mainly in the Post Office organization, however capable and able this may be.

Lieut.-Col. A. G. Lee: A research laboratory ordinarily has three main purposes. The first is the production of knowledge, the second the provision of facilities for testing materials, and the third the development of ideas and inventions. In the telephone industry we are greatly interested in life testing, which frequently enables us to make improvements in the life of plant. As 40 per cent of the rental of a telephone is made up of depreciation, we are naturally interested in the life of the plant installed. In order to co-ordinate the research work with its commercial applications we have set up a committee, drawn from the research organization and the remainder of the headquarters staff, whose business it is to discuss subjects for research, the rate at which the work on these subjects shall be carried out, and, when the research has been finished, whether the results shall be adopted for development. In regard to the optimum sum to be spent on research, research workers tell me that no matter how much is spent on research it will always yield a profit. There must be a limit somewhere, however, and the first limit that one can suggest is that the expenditure on research should be as much as the particular industry can afford. There is also a further test to be applied. The Post Office is an operating, not a manufacturing, organization, and to adopt all the inventions, developments, and suggestions, put up by the research department would be to incur a heavier bill for obsolescence. There are two extremes to be considered in operating a telephone service: (*a*) high tariffs and a system which is very rapidly changing, or (*b*) low tariffs and a slowly changing system which is rather stagnant and inefficient. It is necessary to strike a balance between these two extremes. The amount spent upon research should in the first place be somewhat above the figure which will produce the amount of obsolescence it is intended finally to adopt. Each of the telephone manufacturers in this country maintains a large research establishment, and the amount that they spend in this way must be added to the amount spent by the Post Office on research. Mr. Paterson has suggested that perhaps there should be more communication between Dollis Hill and the workers in the manufacturing and other communications firms. We are out fully to co-operate, and to share the knowledge that we possess with all these other interests. Fairly active steps have been taken in that direction during the past year or so.

Dr. P. Dunsheath: I am particularly interested in the author's references to the early days of the Post Office Research Section, some 25 to 30 years ago. It is a great pleasure to those who knew the old experimenting room at G.P.O. West to see what has sprung from the seed which was sowed there. The Post Office Research Section has done a great amount of pioneer work, and I am reminded particularly of two of its achievements. Mr. Barralet, a Post Office research worker, produced micro-sections of lead cable sheaths showing flow markings, years before the cable makers discovered that there was anything but a perfectly homogeneous mass of metal surrounding the insulated conductors. Again, during the War the Post Office kept the Army abroad supplied with the most up-to-date knowledge of communications research, and added considerably to the value of the important work which was being done by Royal Engineers Signals Corps for ourselves and our allies. There are several questions of research organization to which I should like to refer. I do not agree with the author's and Mr. Paterson's views on the use of indicators for locating investigators in various parts of the laboratory. To disturb a research worker while he is carrying out work which depends entirely upon concentration is to delay the work. Taking him away from his job for 5 minutes to answer a telephone call may mean the virtual loss of an hour of work. The paper deals at some length with life tests, but in some ways these may be misleading. It is not an unknown experience for a subscriber on entering his office in the morning to find that a heavy-handed charwoman has knocked a corner off the telephone. Again, if he is cut off in the middle of an important conversation he rattles the switch hook at a much greater frequency and much more violently during 2 or 3 seconds than at other times in the course of the 12 months. Do the author's life tests provide for such extraordinary incidents as these? I agree with him that the handling of the workshop in a research organization is a matter which vitally concerns all sections of the laboratory. No matter how big the workshop, it is never big enough to handle immediately all the little odd jobs that are brought into it. I have found that a good solution is to continue to keep all the work in the main workshop, but to have that work supervised not only by the foreman in charge, but also to some extent by the director of the laboratory. The supervision of the making of apparatus, and the feeding of the investigators with the instruments they require, may be one of the most important duties of the director. I gather from the paper that the reporting carried out by the department consists entirely of final reports made on the completion of each investigation. Many investigations may occupy months, and some years. I suggest that it is better to insist on the investigators making reports periodically, at intervals not exceeding 1 month, because by so doing they put on record matters which, in the case of a long investigation, may be entirely overlooked. I notice that a special staff is employed for the purpose of producing summaries of the literature, and feeding these summaries to the investigators. I have come to the conclusion that a better way of arranging this work is to make the investigators do their own summarizing. The duty of the central organization should be restricted to distributing the summarizing to the people who are most capable of doing it. In regard to publicity, I suggest that the author should follow the example of the American Telegraph and Telephone Co., who employ a special lecturer, Sergius P. Grace, to bring before the public the latest developments in the research laboratory. The British Post Office is now alive to the value of public goodwill, and here the research side can help considerably. In America the subscriber pays a dollar a year towards research, and the corresponding figure in this country is 9½d. I think we must agree that the British public is getting very good value for its money.

Mr. R. M. Chamney: I am glad of the opportunity of saying a few words at this discussion as I happen to be the only remaining member of the Post Office Research Section who was attached to the old long-distance group associated with research work on long lines. In 1912 we started an intensive investigation into the possibilities of using telephone repeaters, and at that time I was associated with the late Mr. C. Robinson. The Post Office Research Section developed the valve type of repeater, now so well known, from first principles; and perhaps it may be of interest to Mr. Paterson, in view of his remarks, to know that the Section did a great deal of work on valves in the early years. It is interesting to recall that before the War the Post Office obtained from Germany a sample of the old Lieben-Reiz repeater. Shortly afterwards, owing to the outbreak of hostilities, this repeater became a prisoner of war, and in order to complete the investigations on this type of valve we attempted to make samples from it. The first sample valve was being exhausted on the night when the first German Zeppelin reached London, and the vibration due to bomb explosions cracked the glass work of this valve which was being made in imitation of the German sample. The repeater valve which was finally selected was, however, not of the German type, as it was found that a hard valve was an essential factor for stability. Post Office research work progressed in spite of the large amount of time spent during the War on other matters. The Post Office Research Section produced the first commercial repeater station in Europe, which was installed to supplement line plant used for the war communications in this country.

Mr. E. S. Byng: The figures quoted regarding the expenditure on research by the British Post Office and the American Telegraph and Telephone Co. are specially interesting, particularly if one takes them a little farther than the author has done. The figure of 9½d. per subscriber's station spent by the British Post Office is equivalent to approximately £80 000 per annum, whereas that spent in the U.S.A. on a basis of about $1 per annum per station amounts to over £3 000 000. Therefore the total expenditure in this country does not appear to be extravagant. The savings which resulted from 14 of the investigations undertaken by the Post Office Research Station apparently amounted to £160 000, and I presume that, in addition, there must have been some appreciable savings on the remaining 497 investigations which were carried out but not subjected to financial analysis. Furthermore, many of these economies due to improved methods and apparatus introduced as a result of the research would be of a continuing nature. The need for research work in a progressive industry, such as the telecommunication industry, is now generally admitted, but if any specific justification is needed it is amply provided in the figures quoted by the author. There is always the temptation to be guarded against of carrying out research work purely for its own sake, without regard to the commercial aspect. This appears to have been well taken care of at the Dollis Hill Station, which deals mainly with applied research. Applied research necessitates constant co-operation with manufacturing interests and close attention to the many problems which arise in the operating field. I agree with Col. Lee that a limit should be set to the amount of research work carried out. This is particularly so where there is a danger of the manufacturers not getting an opportunity to perfect the processes of production. Perhaps the solution lies in collecting all the improvements resulting from research, particularly in materials and design, and placing them in "cold storage" for application to the industry at predetermined periods. The British Post Office are very considerate in this direction, and do not worry the manufacturer unduly with the incorporation of minor changes which would interfere with production. In addition to the two factors mentioned by the author—namely, the increased annual revenues and the economies to the Department, which are achieved as a result of laboratory work—there are other factors which it is permissible to take into account but which cannot be measured directly in money, e.g. the increased efficiency of the service and the greater efficiency of the staff. Moreover, there is the prestige which the Department and the industry of the country derive from such research work, which is of considerable value. One cannot stress too much the advantage of making public, at the opportune time, the results of investigations which are being carried out by the Post Office with such conspicuous success.

Mr. J. M. Kennedy (*communicated*): The paper is of value in drawing attention to the wide scope of the research work that is undertaken by the Post Office. This work deals with problems that are common to all branches of engineering, and there is no doubt that the present technique of communication engineering contains features by which power engineers could advance their own art. The author points out that the Post Office Research Station takes advantage of research undertaken by other organizations such as the National Physical Laboratory and the Electrical Research Association, and that other organizations make use of the Post Office Research Station. I am not certain, however, that the manufacturers of heavy electrical plant avail themselves as they might of the technical information that has been collected in the field of communication engineering. I should like to take as an example one of the items of research described in the paper. The operation of relay contacts is of vital importance in the power field, and on page 151 six details in the design of contacts are given that have been found to assist towards the satisfactory operation of relay contacts. Of the six points, five are generally disregarded by power engineers. The power engineer in his own field cannot be expected to discover as quickly as the Post Office such details as these. As is mentioned in the paper, the Post Office have in use 500 tons of relay springs; this indicates a rapid accumulation of experience. Power distribution is assuming a national aspect, and power networks extend over hundreds of miles. It has become necessary to install extensive communication networks to control them. I have had the opportunity of seeing communication and power apparatus side by side, and I am driven to the conclusion that the communication apparatus is in certain respects in the more advanced state of development. I should be interested to know whether the author has considered this aspect of the research that is undertaken under his direction, and whether he can suggest any steps by which the attention of power engineers may be drawn to the lessons they can learn from communication practice.

Captain B. S. Cohen (*in reply*): In reply to Mr. Paterson, there is ample room in the individual laboratories to accommodate discarded apparatus which has occasionally to be brought into use. Apparatus for which no further use can be seen is, however, broken up and the individual components are either taken into the store or disposed of. Whilst the use of oil layers on the electrolyte of secondary cells for spray-suppression purposes has proved of great value to the Post Office, it has been found that certain paraffin oils employed can have an adverse effect on the working of the cells. The oil reaches the plates by convection and emulsification during charging and, owing to the presence in it of polar molecules, becomes adsorbed to the metallic sponge lead of the negative plates. The active lead so affected is screened from the electrolyte and does not become discharged until a voltage is reached lower than the normal at the end of discharge. An effective loss of negative-plate capacity is thus caused, which reduces the useful life of the plates. It is noted that a system of loud-speakers for staff location is being installed at the Wembley Research Laboratories. At Dollis Hill, however, an audible signal is not considered advisable owing to possible interference with the work being carried on. The ratio of experimental to non-experimental workers varies considerably in the laboratories of the different research groups. For example, on Telephone Apparatus Transmission there are some 7 research workers, who are assisted by 20 men and 9 women, making a ratio of about 1 to 4, whilst in another group—Materials and Special Measurements—the ratio is about 1 to 2·5. The "R.U. powder" containing traces of the majority of the elements in amounts only just sufficient to reveal their ultimate spectral lines should prove of considerable value for rapid spectral analysis. I assume, however, that Mr. Paterson is not referring to X-ray analysis. I am in full agreement with his concluding remarks and I should like to take this opportunity of explaining what has perhaps not been fully brought out in the paper, namely that the Post Office regards the manufacturing organizations as being primarily concerned with research work in connection with the manufacture of telephone apparatus. There is, perhaps, no need for me to add anything further on this question, as it has also been dealt with in Col. Lee's contribution to the discussion. Col. Lee also refers to the Co-ordination Committee which deals with research and development work generally, and I can confirm that the work of this Committee is of very great value to the Engineering Department as a whole.

Dr. Dunsheath disagrees with the use of staff locators on the ground that they tend to delay or disturb a research worker while carrying out his duties. Those in use at Dollis Hill, however, are devoted entirely to locating the administrative staff who may be visiting any of the laboratories or offices which are distributed over an area of about 8 acres. Dr. Dunsheath refers to what may be described as abnormal ageing effects in connection with life-testing. The life-testing arrangements are of a sufficiently severe nature to cover a certain degree of abnormal usage. It is, however, very difficult to make a life test absolutely representative of all the conditions met with in general use. The speeding up which is essential in life-testing produces in itself certain unknown factors, which in some directions render the life test more severe and in other directions less severe than the normal usage. To a very great extent, however, life-testing is comparative. Certain apparatus which experience has shown to give a satisfactory life under service conditions is life-tested side by side with new apparatus, and if the latter stands up as well as, or better than, the former, it may reasonably be regarded as likely to prove satisfactory in service. With regard to the construction of research apparatus, although it is necessary in certain cases for the director personally to concern himself with the supervision of this work, the items are so varied and numerous as to render it necessary for him to depute this supervision in large measure to a group known as the Construction Group, reference to which will be found elsewhere. With regard to the issue of research reports, the practice in the Post Office is to issue to those primarily concerned an advance report immediately the research has been brought to a conclusion, or at certain intervals during the progress of the investigation. This is followed by the final report, which has a much larger circulation and may in certain cases be supplemented by the issue of appendices and addenda. If an investigation is likely to occupy a considerable time, interim reports which follow the same circulation as a final report are issued at suitable intervals. Dr. Dunsheath refers to special staff producing summaries of literature. It should be made clear, however, that this special staff edits and co-ordinates summaries, the majority of which have been produced by the various specialists. Dr. Dunsheath also refers to the American Telephone and Telegraph Co.'s publicity lecturer, Sergius P. Grace. When in New York I attended a lecture by the latter and can confirm that, judging by the very large and appreciative audience, these lectures must have a high publicity value.

Mr. Chamney mentions the repeater work of the late Mr. C. Robinson; I am very glad to take this opportunity of expressing my appreciation of Mr. Robinson's pioneer work in telephonic transmission, with which Mr. Chamney was also for many years closely associated.

I am in agreement with Mr. Byng's remarks, which do not, however, call for any specific reply.

Mr. Kennedy refers to the relationship between certain aspects of communications research and heavy electrical engineering research. As regards experience obtained in connection with relay contacts, the Post Office would be very glad to place in the hands of the heavy-current engineer the results as embodied in research reports on the subject.

NORTH-WESTERN CENTRE,* AT MANCHESTER, 20TH MARCH, 1934.

Mr. G. G. L. Preece: A paper of this kind is of particular interest to me, because of the family connection I have with the Post Office through my uncle. My father was also in the Post Office, and in his early days was a submarine cable engineer. I can quite imagine that if he could have had available on his ship the precision methods of the modern cable engineer, he would have been saved many anxious days at sea. Although the author gives full credit to the early pioneers, it must be remembered that the intensive research work that has been carried out by the Post Office Research Department, and has made that Department what it is to-day, has been done within a comparatively few years —probably since the War. A few years ago the Post Office might have been said to be lagging behind, but it can now be said with safety that there is no communication system in the world, either telegraph or telephone, that can give a lead to that of the British Post Office.

Mr. F. A. Meldrum: The author is to be congratulated on the choice of the motto he has put over the *porte cochère*; it is pleasing to see that a modern institution like the Research Station has not employed a dead language in its motto. Dealing with the financial aspect of research, the author states on page 138 that 14 cases of the more important type were dealt with during 1932–33, and showed increased revenue, or saving, to the Department amounting to a sum more than double the total annual expenditure. I take it that the charges referred to recur annually, and that the saving will be cumulative. It would be interesting to know what types of cases were dealt with in the special record. The use of the spectrograph for qualitative analysis is of old standing, but its use for quantitative analysis is quite new, and I am very interested in the account of this given in the paper. The fact that it has been generally adopted throughout industry is a point on which the Research Station is to be congratulated. According to a recent paper† the Test Section of the Post Office is now using this method for testing alloy cable-sheaths, and I know of one firm in Manchester which is using it for testing alloy wire. Under the heading "Dielectric Research" (page 142) mention is made of the use of reflecting galvanometers and of the Dolezalek electrometer for d.c. measurements of surface and volume resistivity. A sensitive mirror galvanometer will give satisfactory results of the order of 10^{13} ohms, and an electrometer of the order of 10^{15} or 10^{16} ohms. The use of the electrometer is therefore restricted to the highest-grade material at humidities corresponding to a low percentage of saturation. The continued use of aquadag electrodes for resistivity tests is very interesting to me, in that I first came across this material as a means of forming electrodes at the Rubber Research Institute, about four or five years ago. When brought into use at Dollis Hill it gave considerably more reliable results than the method which had been employed up to that time, namely that depending on the use of lead-foil electrodes. Aquadag electrodes were found to give considerably more intimate contact. One interesting feature of the work of the Research Station staff which is not touched upon by the author is their collaboration in the preparation of British Standard Specifications. I should appreciate some information on this subject.

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* Joint meeting with the Institution of Post Office Electrical Engineers.

† J. Legg: "Stores Specifications and Acceptance Testing," Institution of Post Office Electrical Engineers, Professional Paper No. 148.

Mr. E. S. Rusbridge: In the method of locating faults in submarine cables by the electrode test, I am rather surprised to find that the frequency used is 17 cycles per sec. It would appear that the difficulty of constructing a high-gain amplifier for these conditions is considerable, and it would be of interest to know the factors which have led to the adoption of so low a testing frequency. With regard to teleprinter service to the Continent, mention is made of agreements that will have to be reached owing to differences in alphabets, transmission speeds, etc., between our system and those used over there. The transfer from morse working in this country is recent and of a sufficiently wholesale nature to justify inquiries as to whether any steps were taken in this direction before the transfer was initiated. Perhaps the author can say whether this aspect was considered.

Mr. E. B. M. Beaumont: There is one point the author raised in connection with the financial aspect of the Post Office Research Station which I should like to refer to. I have friends engaged in cotton research with the British Cotton Industry Research Association, and they depend for their livelihood largely on the subscriptions of firms in the trade who are members of the Association. During the past two or three years such firms have been parting with their subscriptions with increasing reluctance, owing to a feeling that the financial outlay was not yielding a profitable return. We are not in the same position. We can definitely point to remuneration accruing from the money expended, and it is very gratifying to the research worker in general to find that one branch of research at least is paying its way. Could the author give some idea as to the procedure adopted in the recruitment of the staff of the Research Station? On what lines is the research conducted, and where do the ideas originate?

Mr. H. C. S. Hayes: The electrode method of localizing earth faults in submarine cables is most interesting and supplies a long-felt want. Our usual a.c. methods of localizing faults in submarine cables, based on reflection from the fault point, do enable us to determine accurately the position of the fault in terms of mileage of cable. This electrode method, however, localizes the fault with reference to the sea bed, and this is really very necessary, because sometimes after two or three repairs have taken place the length increases and the cable does not lie straight on the bed of the sea. In these circumstances, although we may know the distance to the fault in terms of the length of cable, it is very useful to have some positive indication of the fault position. The teleprinter private-wire services are very popular, cheap, and reliable, and I think the designing of telegraph circuits which possess a high degree of reliability under the difficult and exacting requirements of the by-product channels, reflects great credit on the research telegraph engineers concerned. I should like to ask what is the smallest value of cross-talk measurable by the amplifier-rectifier method mentioned in the paper. Recently I was examining the near-end, pair-to-pair, between-quad cross-talk figures for the 1933 Anglo-French submarine cable.* I noticed that the average value quoted for this class of cross-talk was 14·74 népers, corresponding to 128 decibels. It struck me that the measurement of cross-talk of this value was in itself a remarkable achievement, but as this was an average value the instrument must have been capable of measuring something even smaller.

Mr. N. C. Stamford: I note that the cost of upkeep of the cuprous-oxide suppressor is lower than that of the valve type. I should be glad to know whether the higher first cost of the valve-type suppressor is due to the auxiliary apparatus, as I am under the impression that so far as the rectifiers themselves are concerned the cuprous-oxide type has the higher first cost. In regard to the tests involving the deliberate introduction of noise into the system, I should like to know the order of the noise levels it is necessary to introduce; in other words, what level of actual noise has to be dealt with in ordinary telephone work?

Mr. G. A. Cheetham: Has the author heard of, or made, any experiments on metals (particularly silver) melted *in vacuo*? In Europe many claims have been made that vacuum-melted silver has advantages over normally prepared silver; and it would be interesting to know whether the author has any results of work carried out on that class of material.

Mr. T. E. Herbert: The author has naturally said nothing about the work he has done himself over a long period of years. Probably no one else in this country has done so much to place our methods of telephone measurement on a sound scientific basis. Towards the end of the War we had an apparatus by which the position of a hostile gun could be located accurately. The enemy attempted to defeat the apparatus by firing several guns together, but the only effect was to give the position of each particular gun fired. That apparatus was developed by the Research Section of the Post Office from a very crude idea. In general the money spent on scientific research in England produces far greater results than an equal sum spent anywhere else in the world. The vast amount of original research carried out at Dollis Hill under the author's direction has had most valuable results throughout the world, and has been extremely useful to the Post Office districts in this country. It would be difficult to estimate how many years' expenditure on the Laboratory it would take to equal the saving effected even by a single development at Dollis Hill, namely the 2-frequency voice signalling system. On the other hand it is perfectly clear that in difficult times there must be some limit to the amount of money that is spent on research. It is true that in the field of automatic telephony no sooner is an exchange installed than something new is found which is preferred; in other words, immediately a new automatic exchange is completed it becomes more or less obsolescent. Developments in telephone-telegraph engineering are proceeding very rapidly compared with progress on the power side.

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* *Post Office Electrical Engineers' Journal*, 1934, vol. 26, p. 291.

Mr. J. W. Thompson (*communicated*): The author has mentioned that investigations are in progress on the creeping of cables. The usual method of anchoring the cable causes fatigue of the lead sheath at the anchor, and acts only upon the resultant longitudinal motion. It is generally accepted that the creeping motion is caused by vibration due to road traffic, but it does not appear to be recognized that the primary movement of the cable is vertical or nearly so. It is difficult to realize that vibration of this character can cause a length of cable weighing over 2 tons to move at the rate of 2 yards per annum. I should like to refer to the analogous example of an army cable waggon laying out 2 tons of insulated wire, which is picked up with a crook-stick by a mounted man and thrown on to the hedges or other available supports. By this means the man actually raises the whole of the weight and incidentally carries along with him any slack which may have been left at the beginning of the run or *en route*, although the weight on the crook-stick could normally be reckoned in ounces. Loaded cables are often found to creep away from the loading-coil manhole where the heavy main cable is terminated by a plug and joined by smaller cables to the loading coils. The plug is therefore a dead end which can be caused to vibrate vertically by road traffic. The vibration reduces the coefficient of friction on the support and, as the point of vibration moves forward, the vibrating portion of the cable tends to draw to itself the plug and any adjacent slack in the cable. A similar forward wave motion can be obtained by waving the end of a rope which is lying on the ground. It would appear from the foregoing that the logical cure for creeping would be to prevent the vertical vibration or to reduce it to innocuous proportions. An inexpensive method of reducing the vertical movement is that of tightly plugging the space between the cable and the duct with scrap malacca canes about 5 ft. in length, a stout wire being threaded through the manhole ends of the canes to assist in withdrawal. Perhaps the author will state whether anti-creeping devices on these lines have been investigated, and with what result.

Captain B. S. Cohen (*in reply*): Mr. Preece may be interested to know that one of the most treasured possessions in the Research Station Library is what was probably the first experiment book, in which the experiments were written up by various well-known people, including the late Sir William Preece. This book is of considerable value as illustrating some of the early work in the 'eighties on telephones.

Mr. Meldrum is right in assuming that the figures on the financial side of the station's work are annual charges. Each would be effective for a certain number of years and would of course be cumulative. The types of cases selected are covered by the list given on page 138. With regard to collaboration in the preparation of British Standards Specifications, it may be stated that the Research staff are well represented on the various Committees of the British Standards Institution.

With reference to Mr. Rusbridge's remarks on the electrode test for locating faults in submarine cables, a very low frequency was chosen because of the necessity for getting the minimum electromagnetic screening due to the presence of either steel armouring wires or lead sheaths. The difficulties in constructing a high-gain amplifier tuned to 17 cycles per sec., although considerable, were not found to be insuperable. With reference to the standardization of teleprinters, this has been a case where a mechanism has been developed along somewhat parallel lines by competing organizations; the difficulties of co-ordination in the preliminary stages for such cases are generally insurmountable. The co-ordination of teleprinter alphabets, transmission speeds, etc., is, however, now being carried out by the International Consultative Committee on Telegraphs. The regenerative repeater referred to in the paper provides a device which can be inserted at an international boundary, and which would reduce to some extent the difficulties mentioned.

Mr. Beaumont refers to the recruitment of research staff. This is on the normal Post Office Engineering Department lines. A recent modification, however, in the recruitment of assistant engineers was first applied to the Research Section and is found to offer considerable advantages. The applicants for these appointments must have an Honours B.Sc. degree in either engineering or physics, and are then selected by a board by oral examination. Mr. Beaumont also asks on what lines Post Office research is conducted and where the ideas originate. Many investigations are the result of specific troubles arising in the general operation and maintenance of the communications plant. Others are in connection with the introduction of new systems, new facilities, etc.

Mr. Hayes mentions one very important advantage of the electrode method of testing submarine cables, in that the fault is localized with reference to the sea bed and not in terms of distance along the cable. With regard to the objective method of cross-talk measurement, this is limited by the fact that the lowest values measured by aural methods would require such an amplification for a visual measurement as to bring in difficulties due to thermal agitation.

In reply to Mr. Stamford, there is very little difference in first cost between echo-suppressors of the valve and the valveless type. What there is, however, is in favour of the valveless type. He also asks what level of actual noise is to be dealt with in ordinary telephone work. It has been proposed to accept a noise-level such as produces a loss not exceeding 5 per cent in syllable articulation. With certain frequencies, however, such a noise-level is very obvious when introduced into a telephone circuit; this noise-level is of the order of 1/500 microwatt. This is as regards line noise. With regard to room noise, telephones may be required to operate at noise-levels covering a range of from about 35 decibels above threshold, representing a quiet room in a suburban house, to busy city offices in which the noise-level may exceed 60 decibels.

In reply to Mr. Cheetham, our researches have been carried out with 99·9 per cent pure silver for contact work. We have not tried silver prepared *in vacuo*.

Mr. Herbert refers to the rapidity of development in telephone and telegraph engineering resulting in what is, undoubtedly, an alarming rate of obsolescence; this difficulty has also been referred to by Col. Lee and Mr. Byng in the London discussion. The rate of development can to a very great extent be controlled by limiting the amount available for expenditure in research in any particular direction; I regard this method as preferable to any arbitrary limitation of the total annual expenditure for a research organization, as circumstances frequently indicate the desirability of carrying out extensive and possibly expensive investigations in some branch of the work which is lagging behind.

Mr. Thompson's contribution to the discussion on cable creepage is of considerable interest. Investigation has led us to the conclusion that the vertical vibration of cables is the real cause of their creeping in a horizontal direction. Experiments are actually in hand to measure the amplitude of this vibration in certain typical cases of cables under roads carrying heavy traffic. In some such cases the stresses set up in the cable sheathing are such that it has been found necessary to hold the cable with specially designed grips at every manhole.

NORTH-EASTERN CENTRE, AT NEWCASTLE, 9TH APRIL, 1934.

Mr. B. A. Robinson: During my early days of training at the General Post Office, St. Martin's-le-Grand, it was my privilege to visit the National Telephone Co.'s laboratory at Telephone House, as well as to see some of the telephony tests made at the G.P.O. Thus my thoughts go back to the old Decket transmitter, the original Bell-type receivers, and the noisy lines in use at that time. One of the main links between the crudeness of the telephony of those early days and the high standard of perfection existing to-day is the Dollis Hill Station and its forebears. The paper is a description of a lavishly conceived but fully justified organization, excellently housed. The whole lay-out, together with its staff organization, has entailed an immense amount of thought, coupled with years of accumulated experience. I should like to congratulate the Post Office on their broad vision in seeking co-operation with other established research laboratories, both national and private. I hope, however, that the administration will carry this farther and let the public have more statements as regards their work. In many quarters the idea seems to be firmly rooted that our American cousins are doing most of the development work which is being carried out in telecommunication. The author mentions the use of spectrographic methods of analysis; I should like to know whether the Post Office have yet used the method of diffraction by electronic waves. This method is arousing appreciable interest at the present time. In the local Press this morning it was stated that the new telephone kiosks which have been installed in two villages in the North of England provide continuous day-and-night telephone service, and enable callers to speak to any subscriber either in the British Isles or overseas. I should like to ask whether these last words are correct.

Mr. W. F. Smith: A large amount of research work involves the question of devising some means whereby apparatus can be made to last much longer than the period for which it was designed. In this respect the Post Office Research Section appear to have succeeded at an early stage, since they found it possible to utilize army huts as accommodation for a period of about 10 years as against the predicted life of 5 years. The rapid strides which have been made in recent years in world-wide communication engineering are due in no small measure to the Post Office Research Section. The paper gives a good idea of the diversity of subjects with which the Dollis Hill Station has to deal. It is probably the comprehensive nature of its work which has made the station second to none in this country. The reason why the Post Office is unique in being able to show a profit in connection with research is that the greater part of its work is applied research. I should be glad to know the extent to which investigations of a pure research character are carried out at Dollis Hill. The author makes no reference to investigations in connection with rectifiers. This omission is surprising in view of the very prominent position now occupied by the rectifier in electrical engineering. The question of utilizing rectifiers to replace secondary batteries at telephone exchanges is now worthy of some consideration. The capital cost of the former is probably lower, and the space required is very much less than that occupied by secondary batteries, whilst running cost and ease of maintenance would undoubtedly indicate a preference for rectifiers. The power-supply leads and telephone lines appear to be terminated at the laboratory benches on a common panel. This is a departure from usual practice, and I should be glad to know whether any special protective devices are fitted. If so, what is their nature? It seems to be a retrograde step to install electric clocks of the type which is driven from a master clock. The use of clocks of synchronous type would have given much valuable information as to their reliability for general use in telephone exchanges. The apparatus for testing cables for electrolysis is extremely ingenious, but it does not seem sufficiently robust for roadside tests. One is invariably called upon to make such tests on roads carrying very heavy traffic, and extremely robust instruments would appear necessary. Presumably the motor driving the photographic film is worked from a battery. Life tests have of necessity to be carried out under conditions differing very widely from those of actual practice. Difficulties arise in regard to temperature effects on component parts of the apparatus; atmospheric conditions vary from day to day and from place to place, and, perhaps more important, the ratio of operating period to rest period is extremely high in the tests. Life tests cannot give us a true indication, but it is probable that the "life" as given by the tests would be shorter than that actually obtained in practice.

Are any data available to indicate that life tests do in fact give a reliable indication of the performance of the apparatus? Is it necessary to make life tests? In these days when the introduction of new features is almost of daily occurrence we often find that plant has to be scrapped before the end of its life, in order to keep abreast of development. The author refers to the fact that a life of only 2 years is obtained for galvanized stay wire in South Lancashire. This does not convey very much unless a standard of comparison is given; perhaps the author would indicate what life may be expected under average conditions. The patents organization, mentioned on page 151, is, I think, chiefly devoted to examining existing patents and keeping in touch with new ideas. It would be interesting to know the number of patents taken out by the Post Office Engineering Department annually.

Captain J. E. Fletcher: The arrangement and general organization set up at Dollis Hill are a bright and glaring example of wise administration and organizing ability on the part of the engineer. Although the organization may be costly it could be easily shown that, quite apart from the economic aspect, the Research Section does a work and carries out investigations which cannot be computed in terms of money. I refer to investigations of troubles in connection with materials, electrolysis, etc., which, unless they were carried out at Dollis Hill, would have to be carried out in the field. In this respect alone the organization is well worth while. In the building described by the author accommodation has been provided for almost every branch of telecommunication with the exception of television. Is the latter a considered and deliberate omission? The author mentioned an interesting point regarding creeping cables. I have known of two or three cases of cables creeping uphill, and was under the impression that the creeping was due to vibrations set up by fast-moving traffic combined with the weight of that traffic, but not solely due to the latter contingency. The author may, however, have definite information on the subject. With regard to the paint-spray research done at Dollis Hill, is the investigation in connection with the efficiency of spray painting or does it refer to the spray painting of wood and iron work? If the former, I should be glad to know what the author thinks of the system, and whether spray painting is likely to become a successful proposition so far as Post Office engineering work is concerned.

Mr. A. C. Smith: The paper demonstrates that British telephone engineers are doing their utmost not only to maintain a leading position as compared with other telephone organizations but also to improve the known means of communication. It has long been a theory of industrial economics that combinations of firms, and monopoly businesses, have the outstanding advantage of having all scientific and technical operations under the control of experts, so that gains may be expected from the pursuit and application of scientific research and technical invention. The Post Office services are monopolistic but their economics are their own, owing to the Treasury control. The author has said that he can save twice as much money as is given to him, and no doubt the Research Station is casting covetous eyes on the £13 100 000 which I understand is the Post Office surplus this year. Having regard, however, to the financial stringency consequent upon the heavy demands made upon H.M. Treasury, I suggest that all the more credit is due to the staff of the Research Station for their efforts and for the results which they have achieved.

Mr. C. Turnbull: The author's remarks on lead corrosion make one hope that the magnificent researches of the Dollis Hill Station will be used to find out a means by which the lead may be made immune or protected from corrosion. It is obvious that a large town cannot maintain its area free from electric currents, particularly where there are electric tramways and railways in the district. The Post Office is a non-paying guest in our streets, and it seems unreasonable that those who contribute to the upkeep of the streets by paying rates should also pay for any corrosion that may take place in the lead cables of those who do not pay rates. The author's remarks upon the corrosion of stay wires in industrial districts are important, seeing that the corrosive atmosphere has to be breathed by human beings. Years ago Kelvin pointed out that the operations of men were being carried out on such an increasing scale that the very atmosphere itself was being affected. Every time we burn a ton of coal or of oil, we also consume the equivalent amount of oxygen. Kelvin recommended that mankind should grow sufficient vegetation to restore the oxygen to the atmosphere. The time has come when research should be made on the debilitation of the atmosphere owing to the operations of humanity.

Captain B. S. Cohen (*in reply*): Mr. Robinson refers to the use of diffraction by electronic waves for research purposes. This method has not yet been employed at Dollis Hill. Its main advantage would appear to be in connection with the study of surface and skin phenomena, as the penetration of the electrons is so much smaller than that of X-rays.

No special kiosks such as Mr. Robinson mentions have been installed. The present arrangements are that calls will be accepted from any kiosk for any British or Continental subscriber, but if a call is put in necessitating the use of a radio link the caller will be asked to apply at the nearest counter office at which such calls are accepted, the address of such office being given him.

Mr. Smith asks as to the extent to which investigations of a pure research character are carried out at Dollis Hill. As has been pointed out in the paper, the Post Office Research Station is primarily an organization for applied research. In a few cases, however, it has been found necessary to carry out what may be described as pure research work, and a strictly limited number of such cases is always likely to recur. Mr. Smith also refers to research work on rectifiers. Quite a considerable amount of work of this nature is constantly being carried on, the Materials Group dealing with the specific properties and characteristics of various types of rectifiers, and most of the other groups investigating the applications of such rectifiers. He also asks about protective devices on the power-supply leads. These are protected by fuses at the main distribution points and at the individual bench panels. With regard to apparatus used for testing the current leaving cable sheaths, this is actually quite robust. One of the principal requirements in mind when this apparatus was developed was that it should be capable of being used by the roadside. Records are taken satisfactorily with the apparatus standing on a pavement within a few feet of a roadway carrying heavy traffic. I am in agreement with some of Mr. W. F. Smith's remarks as regards life-testing, and further reference will be found in my reply to Dr. Dunsheath in the London discussion. With regard to the life of galvanized stay wire in South Lancashire, it can be stated that in rural conditions the life of a good galvanized wire (No. 8 S.W.G.) should be well over 20 years, whilst in urban or semi-industrial areas a life of 10–15 years may be expected. Mr. Smith is right in assuming that the patents organization mentioned on page 151 is chiefly devoted to the examination of existing patents and to keeping in touch with new ideas. The number of patents actually taken out by the Post Office Engineering Department annually is quite small.

Captain Fletcher refers to the fact that no specific accommodation is allocated to the study of television. Although no special provision has been made up to the present, some such provision may be required in the future, more particularly as the Postmaster-General has quite recently set up a committee to study the commercial applications of television. Spray painting is in general use in connection with the production of research models. It may be stated that a considerable amount of telephone and telegraph equipment is, and has been for years, spray-painted.

SCOTTISH CENTRE, AT GLASGOW, 10TH APRIL, 1934.

Mr. C. H. Whillis: My earliest recollections of the Research Section of the Post Office, some 35 years ago, was that its work was carried out in a very apologetic way. The only fault I have to find with its work to-day is that it is much too prolific, and scarcely gives the executive staff time to apply the results of the researches in the field. There is no doubt, however, that the work carried out by the Research Department has resulted during the last few years in placing the British Post Office, in connection with telegraphic and telephone communication, in the forefront of the nations of the world.

Mr. H. Smith: More than 20 years ago I was engaged with the author on work in connection with line transmission. The distance at which the subscriber speaks from the mouthpiece of the instrument has an important effect on the transmission value of the connection over which he is speaking, and at the period to which I refer the author was engaged in measuring a large number of subscribers' heads, in order to determine the design of instrument which could be most efficiently used. The present-day design ensures an absolute minimum of separation. With reference to the palladium-chloride gas detector, I have actually used this device and can testify to its great efficiency. Gas leakage is a problem with which not only the Post Office but also other concerns dealing with electric lighting and power services, or with any other plant which necessitates the use of conduits and underground jointing chambers, are continually faced. The vibration due to the large amount of traffic on the roads will tend to cause more and more escapes from gas mains. The palladium-chloride gas detector will therefore prove of increasing value.

Mr. W. Cruickshank: On page 133 it is mentioned that the initiation of the new station was due to Mr. S. A. Pollock; I should like to add that it was the author himself who carried the work to fruition. The fact that the Post Office built a station of such an impressive character is due to the persistent efforts of some half-dozen individual members of the Service. The Treasury annexes all the profits of the Post Office, but last year the Post Office secured the privilege of taking back 10 per cent of the profits for the purpose of development. This is a step in the right direction, and the money will be spent to the best advantage in stations like Dollis Hill, and in the general improvement of the public service.

Mr. J. B. Mavor: Has any special research work been done with regard to the privacy of the use of the new receiver? I find that if the correspondent is a loud speaker everybody in the room can hear his responses. It would be a big improvement if the new type of receiver could be modified so as to give privacy of conversation, without affecting the standard of reception.

Captain B. S. Cohen (*in reply*): Mr. Whillis mentions the difficulties due to the rapid rate of development in tele-communication methods and apparatus, and this has also been stressed by other speakers.

Mr. Harvey Smith refers to early work in connection with the measurement of human heads, with particular reference to the distance between the ear and the mouth, in order to determine what would be the modal* distance between a speaker's mouth and the mouthpiece of the transmitter in particular forms of combination telephones. Measurements of this sort are still being made, and the results of many thousands of measurements in different countries are at present being considered by the International Consultative Committee on Long-Distance Telephony in connection with the co-ordination of transmission results.

Mr. Mavor pays tribute to the very high efficiency of the new hand-combination telephone. I suggest that it would be better in the cases he mentions to ask the speaker to talk more quietly rather than to reduce the volume efficiency of the telephone.

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* The term "modal" has been adopted as describing the position, both as regards distance from the mouthpiece and direction of speaking, of the mouth of the average subscriber.

THE INFLUENCE OF THE BENSON BOILER ON THE DEVELOPMENT OF POWER STATIONS.

By F. OHLMÜLLER, Dipl. Ing.

(*Paper received* 1*st December*, 1933; *read at a Joint Meeting of* THE INSTITUTION *and* THE INSTITUTE OF FUEL, 15*th February*, *before the* NORTH-EASTERN CENTRE 12*th February*, *and before the* NORTH-WESTERN CENTRE 13*th February*, 1934.)

SUMMARY.

The paper first deals with the evolution of the Benson boiler and then proceeds to detail the steps taken to enable it to be used for commercial purposes, first at critical and later at sub-critical pressures.

The present design of the boiler is next discussed and it is claimed that a considerable saving in weight and cost is obtained with it as compared with ordinary water-tube boilers. A brief discussion of the probable future development of the boiler follows.

The operation of the boiler at variable pressure is next dealt with. Finally, some figures of cost are given and the advantages and possibilities of the boiler are summarized.

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(1) THE BENSON BOILER FOR CRITICAL PRESSURE, AND ITS DEVELOPMENT INTO A TUBULAR BOILER FOR ALL PRESSURES.

As is well known, the latent heat of water at the critical pressure (3 200 lb. per sq. in.) is zero, and the water on being heated to the critical temperature (706° F.) turns completely and instantaneously into steam. Separation of the steam from the water, such as takes place in the drums of ordinary boilers, is not therefore necessary, but dry steam is produced with certainty in tubular boilers without drums. This was one of the arguments put forward by Mark Benson in favour of his invention. The second argument was the high thermal efficiency which can be obtained by the utilization of the high-pressure steam in prime-movers, which at the time of Benson's invention was a point of general interest. The trend towards higher steam pressures was also noticeable in the construction of ordinary water-tube boilers. The circulation of the water in ordinary water-tube boilers depends, however, upon the difference in specific gravity of water and steam, and this difference diminishes as the pressure increases. Thus an upper limit of pressure is soon reached in water-tube boilers of the ordinary type.

The utilization of the Benson boiler for commercial purposes was at the outset accompanied with difficulties. The first experimental boiler installed at Rugby no doubt delivered dry steam, and no difficulty was experienced in distributing the flow among the tubes connected in parallel, but burning-out of a tube occurred after the boiler had been in operation for some time. As a result of prolonged systematic tests carried out subsequently on Benson boilers built in Germany, it was found that the burning-out of the tubes was caused by the precipitation of salts contained in the feed water in those parts of the tubes where the water changes into steam. In the Benson boilers built before the discovery of this fact, the conversion zone was placed in the region of maximum intensive available heat radiation, in order to secure a counterflow. The tube failures, therefore, were entirely due to the deposition of salt, which diminished the rate of heat transfer from the metal wall to the fluid inside, thereby raising the temperature of the tubes.

After the recognition of the influence of the salt deposits, a remedy was found in the removal of the affected parts of the heating surface from the radiation zone to the region of lower flue-gas temperatures. This innovation was the means by which the two Benson boilers at the cable works of Messrs. Siemens-Schuckert, and the Benson boiler which Messrs. Blohm and Voss had fitted in the steamer "Uckermark" of the Hamburg-American line, were, in every respect, rendered reliable for continuous operation.

If the salt content of the feed water is very high, or the boiler is in operation for a long period, an arrangement is provided for scavenging the tubes while the boiler is in operation. During the scavenging, the output of the feed pump is increased and a corresponding quantity of water is allowed to escape from the boiler after having passed through the bundle of tubes in which salts had been deposited. The total heating surface is subdivided into a number of groups of parallel coils, these groups being scavenged one after another, so that the generation of steam, as a whole, is not affected by the cleaning process. This scavenging closely resembles the blowing-down of ordinary boilers, the only difference being that, owing to the higher permissible concentration, the quantity of water to be blown down from the Benson boiler is much smaller. With pure feed water, even after weeks of continuous operation, no scavenging is necessary, as was proved, for instance, in the case of the Benson boiler on board the s.s. "Uckermark" on her long voyages.

Following the success obtained with Benson boilers at the critical pressure, Messrs. Siemens-Schuckert applied the experience gained in the operation of the Benson boiler at pressures below the critical. Tubular boilers as such, operating at sub-critical pressure, are known, but none of these, e.g. the Perkins, Serpollet, and De Laval boilers, could be developed for larger outputs. Tests have shown that here also—as in the case of critical pressure—the difficulty lies in the formation of salt deposits in a certain zone of the heating surface. It was found that this zone is at the point where evaporation terminates and superheating begins, and is clearly restricted to a limited portion of the heating surface. Here, again, the remedy consisted in shifting the zone of deposit to a region of lower flue-gas temperature.

Investigations to ascertain the behaviour of the salts were first made on a small experimental boiler at the Siemens-Schuckert cable works with feed water containing various salts and of different concentration and combination. Fig. 1 represents the readings over an hour taken from a large series of tests, and shows the salt concentrations and temperatures at the boiler outlet. The boiler was operated under very fluctuating conditions of temperature at the measuring point, and it will be seen that here the salt content of the steam varies inversely with the temperature, dropping to 10 milligrams per litre at temperatures above the critical and rising to about 300 at lower temperatures. The tests proved conclusively that the only time when precipitation of the salts on the walls of the tubes takes place is shortly after the conversion of the water into steam, i.e. when superheating commences.

The same tests were repeated at a later period at subcritical pressure, with the same result. After this knowledge had been gained, the larger of the two Benson boilers at the Siemens-Schuckert cable works was modified accordingly for sub-critical pressure, and the boiler of the "Uckermark" was also arranged by Messrs. Blohm and Voss for sub-critical operation. Since then both boilers have been in operation for many months without the slightest hitch, so that the reliability of operation at subcritical pressure under actual working conditions is now an established fact.

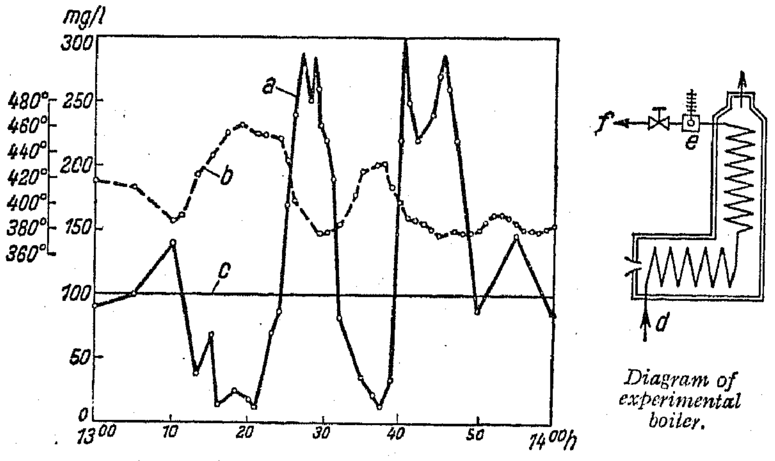


Diagram of experimental boiler.

a=salt content, b=temperature, c=salt content in the feed water, d=feed water inlet, e=measuring point at superheater outlet, f=steam outlet.

FIG. 1.—Salt test on Benson boiler.

As all the experience gained with, and the designs developed for, the original Benson boiler, are utilized for the tubular boilers with sub-critical pressures according to the patents filed by Siemens-Schuckert and the Internationale Benson-Patentverwertungs A.G., the name "Benson boiler" was retained in general for the tubular boilers of this type. According to their size and the purposes for which they are to be used, the Benson boilers to be built in the future will be designed for critical or sub-critical pressures. For base-load plants and where fuel costs are high, the critical pressure will be chosen with a view to maximum economy. For smaller plants or for peak-load stations, operation at sub-critical pressure is preferable. For the correct choice of pressure there exists a simple rule of thumb to the effect that the pressure (in atmospheres) should be set as high as twice the number of tons per hour capacity. Thus for a plant having a capacity of 100 tons per hour the approximately correct pressure at the turbine stop-valve is 200 atmospheres; again, if the output is only 20 tons per hour, the working pressure should not exceed 40 atmospheres. It is also possible to operate the Benson boiler with variable pressures within the limits, for example, of 50 to 180 atmospheres, a method of working which will again be referred to later.

(2) THE PRESENT-DAY AND FUTURE DESIGNS OF THE BENSON BOILER.

The Benson boiler is characterized by the absence of drums and the freedom thereby obtained in the arrangement of the tubes and the general lay-out, which can be entirely based on the structural requirements and the method of firing to be used. Owing to the omission of drums a considerable saving in weight and cost is obtained as compared with ordinary water-tube boilers. A further saving is obtained by the fact that, by reason of the narrow tubes employed, the weight of the heating surfaces is smaller than in normal boilers, in which, on account of the natural circulation, much wider tubes are necessary than for the Benson boiler with its forced flow. The saving in weight achieved by the use of smaller tubes is shown by Fig. 2. In the Benson boilers hitherto built tubes of 20- to 30-mm bore are used.

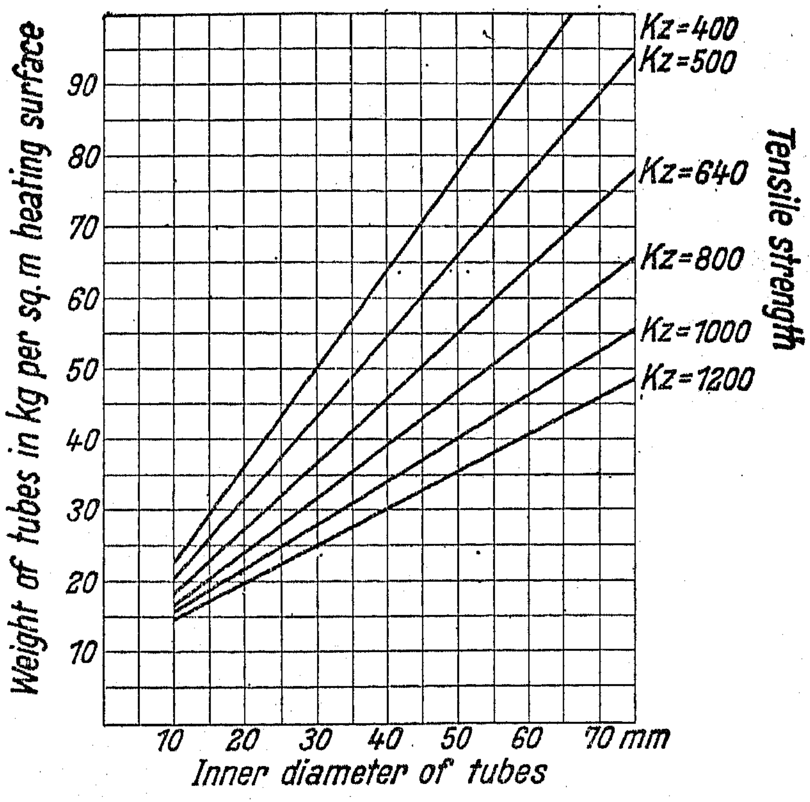


FIG. 2.—Weight of tubes per square metre of heating surface, as a function of the tube diameter.

For very small outputs a Benson boiler may be formed of a single continuous tube. For commercial outputs, however, a subdivision into a number of parallel rows of tubes is indispensable. The number of tubes connected in parallel, and the velocity of flow resulting therefrom in the tubes, may be chosen freely, the choice being restricted only in that, on the one hand, the pressure-

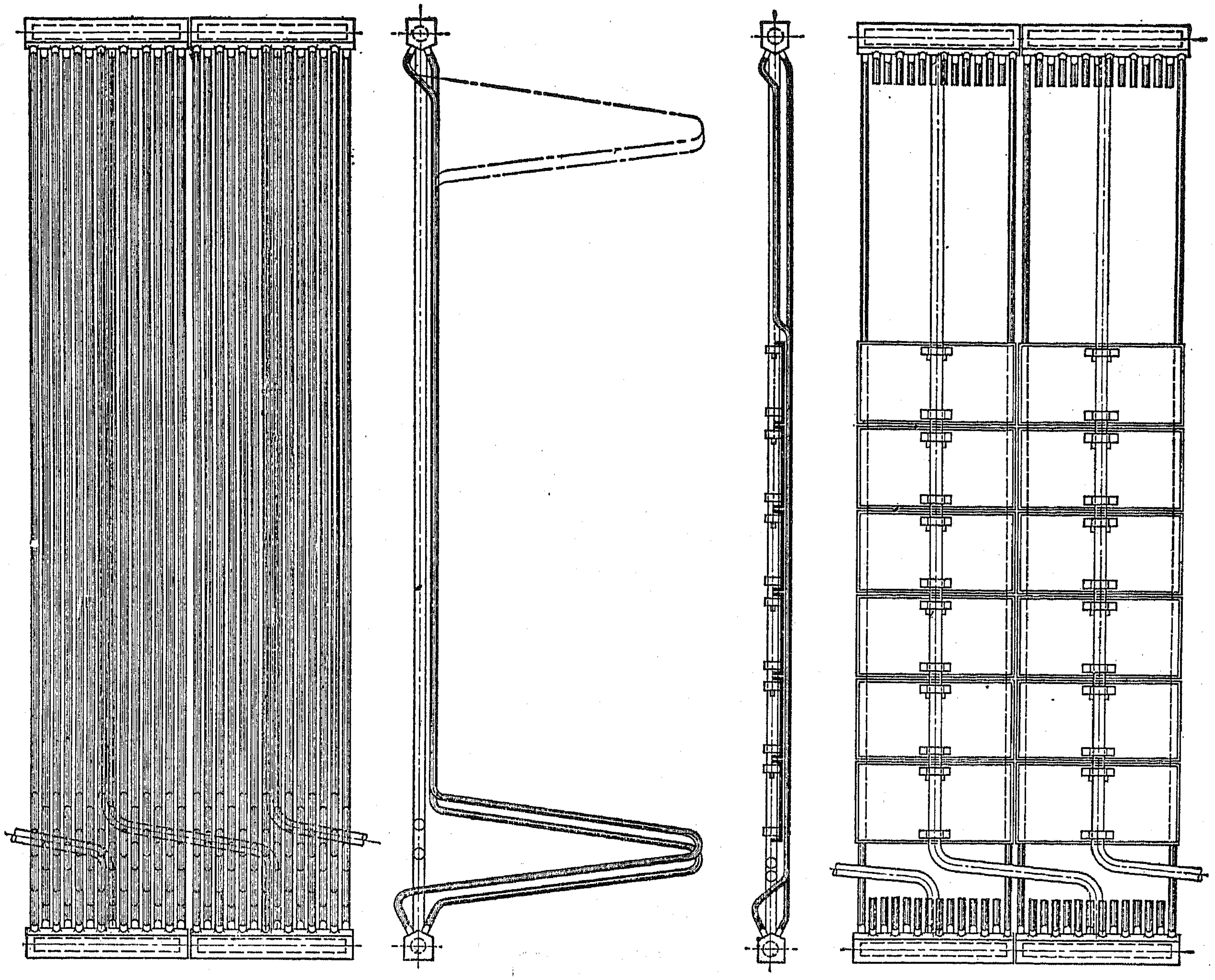


FIG. 3.—Radiation heating element of a Benson boiler.

drop at the higher velocities should not be too great, whilst on the other hand the cooling effect of the moving fluid on the tubes should not be diminished. Large differences in the distribution of the medium among the various parallel tubes have not hitherto been observed.

On the basis of the experience gained, simple standard designs have been developed for the essential parts of the Benson boiler. The parts forming the heating surface are grouped to form normal elements, which are differently designed according to whether they are intended for the radiation part or for the convection part of the boiler. The elements for the radiation part consist either of coiled or of straight vertical tubes with headers at the lower end and collectors at the upper end, and of down-tubes leading to the next element (see Fig. 3). The elements of the convection part consist of separate coils wound clockwise and counter-clockwise, which together form heating elements when inserted into one another. These are provided with supports at the return bends and are built into the boiler as a whole (see Fig. 4).

The general construction of the Benson boiler will, in many cases, resemble that of normal boilers. This is the case with the Benson boiler with a chain-grate stoker, shown in Fig. 5. The oil-fired Benson marine boiler of the s.s. "Uckermark," Fig. 6, also approaches the ordinary boiler in form. A special design whereby boiler-house costs are reduced was adopted in a few cases for the Benson boiler when it could be erected in the open. This, however, is not an essential feature of the Benson boiler but is merely a type of design to which the boiler readily lends itself.

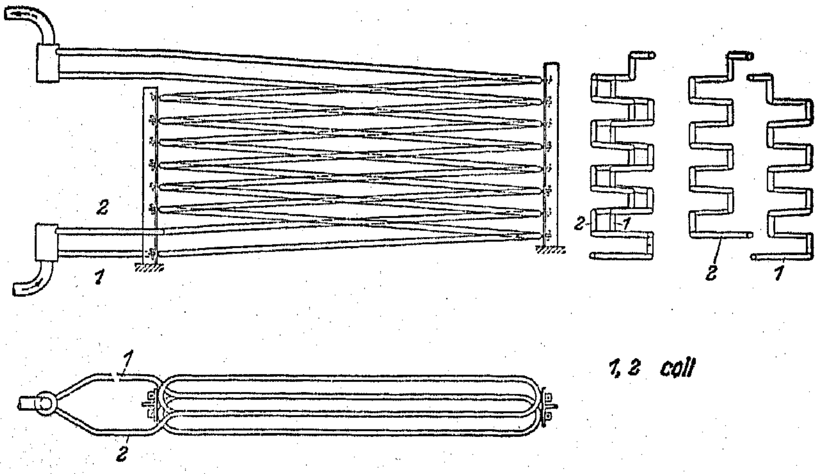
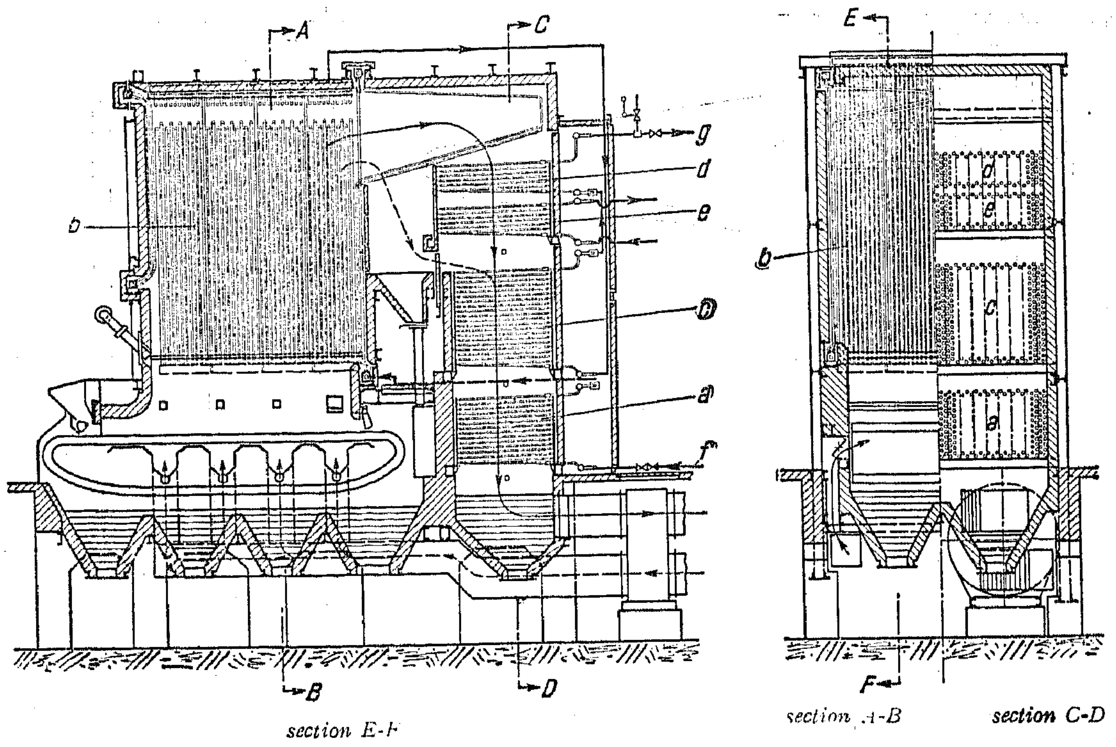


FIG. 4.—Convection heating element of a Benson boiler.

The boiler at Langerbrugge (Fig. 7) is an example



a=economizer, b=radiation zone, c=conversion zone, d=superheater, e=reheater, f=feed water inlet, g=steam outlet.

FIG. 5.—Benson boiler with chain-grate stoker and auxiliary pulverized-fuel firing.

of this type of construction. Originally, the heating surface in the radiation part of this boiler consisted of coiled tubes. Owing to the large dimensions of these coils the heat expansion caused a certain displacement of the tubes. For this reason the coiled tubes at Langerbrugge were recently replaced by elements with straight tubes similar to those shown in Fig. 3. In the lateral flues are placed the bundles in which the conversion of the water into steam takes place. The partition between the furnace and the second flue consists of cast-iron plates fastened to the tubes, so that the use of brickwork and refractory is reduced to a minimum, as will be seen from the illustration of the radiation heating-element (Fig. 3).

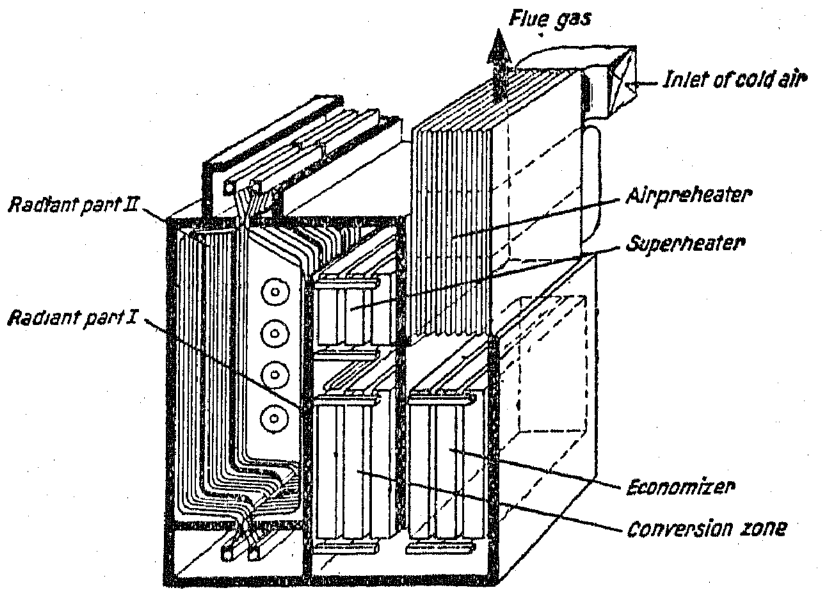


FIG. 6.—Oil-fired Benson marine boiler on S.S. " Uckermark," output 20 tons per hour.

According to the space available, Benson boilers may be built as single-pass boilers on a comparatively small floor area and with a great height, or as two- or three-pass boilers, which are lower but of greater length or breadth. A number of possible solutions are shown in Fig. 8.

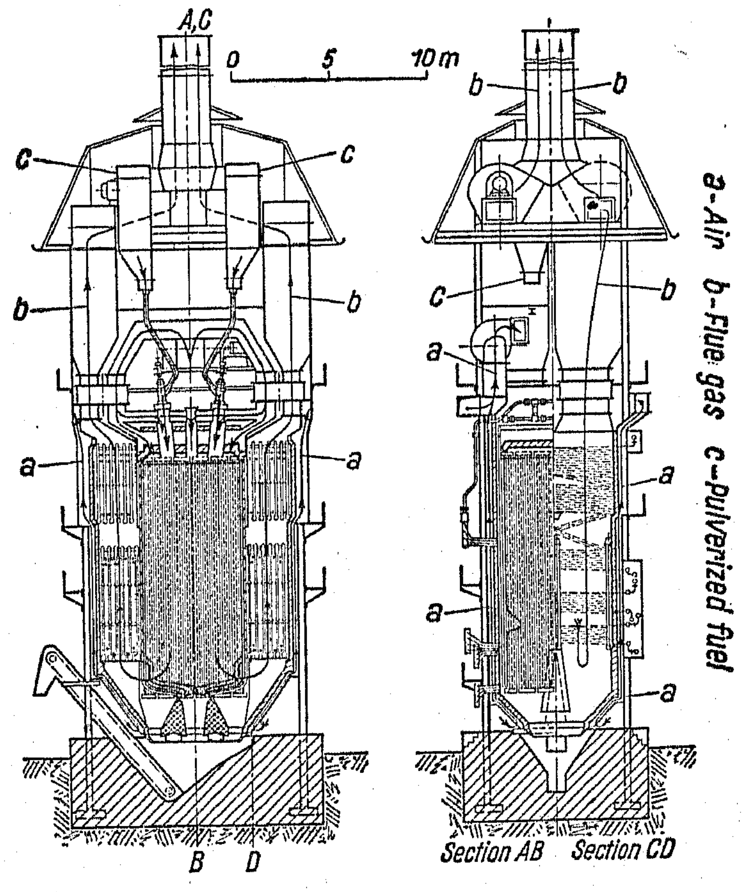


FIG. 7.—Section through pulverized-coal-fired Benson boiler at Langerbrugge, output 100–135 tons per hour.

(3) OPERATION OF THE BENSON BOILER AT VARIABLE PRESSURE.

Before entering into details of the new method of operating boilers at variable pressure (made possible by the Benson boiler) the development of the steam boiler will be briefly outlined (see Fig. 9). Originally, steam was generated in a simple vessel. In the course of development the steam was not so much produced in the vessel proper as in the tubular heating surfaces which were first added to it, and finally replaced it entirely, leaving as the only duty of the vessel (drum) the separation of the steam bubbles from the mixture of water and steam. At the same time the pressure was more and more increased and the water storage-capacity reduced. The end of this line of development is the standard steam boiler of the inclined-tube (sectional header) or steep-tube (Stirling) types, or the radiant-type boiler with largely water-cooled furnace walls. Parallel with this development of the boilers, the furnaces were developed from the simple grate to the present-day mechanical stokers, the air pressure being moderately increased at the same time. In course of time, the economy of the boiler was further improved by the addition of the economizer. An idea which might perhaps have led to the forced-flow boiler was embodied in the steaming economizer, in which the water was heated until a partial evaporation took place. As boilers increased in size and pressure, difficulties arose in maintaining the natural circulation of the water. It was to counter these difficulties that special types, such as those of Schmidt, Löffler, and LaMont, were developed.

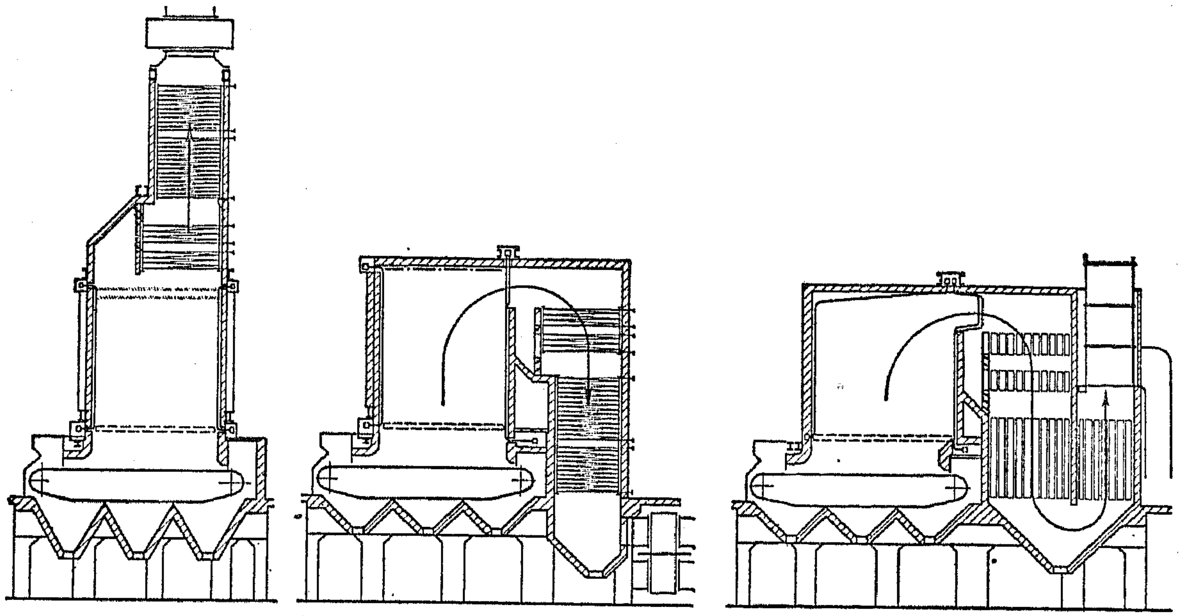

Single-pass boiler. Two-pass boiler. Three-pass boiler.

FIG. 8.—Various designs of Benson boilers with chain-grate stokers.

Along with the development of the ordinary steam boiler, endeavours were made to build efficient tubular steam generators, which date back as far as the early days of boiler construction, but in spite of many efforts this did not lead to any satisfactory solution for boilers of large output until the appearance of the Benson boiler. The Benson boiler, as a representative of the forced-flow type and operating at the highest pressure, stands at the end of this line of development.

Until recently, the pressure in steam boilers was regarded as a constant determined by the boiler construction; and for reasons of economy it was chosen to be as close as possible to the maximum value with respect to material stress. In Fig. 9 this period of development is marked by a line. The Benson boiler goes beyond this line, since it may be operated not only at the highest possible pressure but also at any other desired lower pressure, even at pressures varying during operation. This independence upon constant pressure is possible owing to the fact that the boiler consists merely of tubes and has no drums or large containers. The Benson boiler for different and variable pressures, therefore, seems destined to initiate a new movement in the generation of steam power.

At the instigation of Mr. Gleichmann, Messrs. Siemens-Schuckert developed a new method of operation of steam power-plants. This consists in omitting the throttling of the steam between the boiler and the turbine. In this way the Benson boiler always delivers steam at the most economical pressure consistent with the load at which the turbine happens to be operating.

The theoretical proof of the feasibility of operating the boiler at variable load is illustrated by the total-heat/temperature diagram (Fig. 10). The condition to be fulfilled is that with varying load the distribution of heat in the various sections of the heating surface of the boiler should be such as to ensure that at all loads those parts of the heating surface subject to deposition of salt remain in the desired region of flow of the flue gases. In Fig. 10 the conditions obtaining when the boiler is operated at critical pressure are shown by the

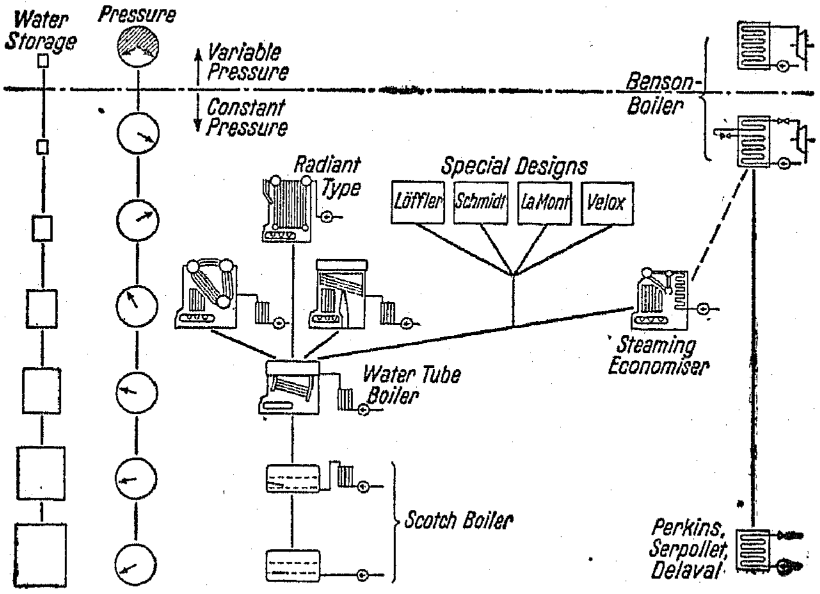


FIG. 9.—Development of the steam boiler.

dotted line. Following the saturation curve, the water at critical pressure (3 200 lb. per sq. in.) is brought up to the critical temperature and then superheated beyond that to about 850° F., whereupon the steam is throttled down to 2 500 lb. per sq. in. and again superheated to 850° F. This was the method of operation in the plant at the cable works before the boiler was operated at sub-critical pressure. The full lines show the working of the boiler at sub-critical pressure. According to the pressure, the curve remains more or less within the region of saturation. The region where the bundle of tubes is situated, in which the conversion of the water to steam takes place, is shown by the thin dotted line. It will be seen that, even when the pressure varies, the saturation curve always remains approximately in the middle of that region. This method of operation was first tried out at the Siemens-Schuckert cable works, where the boiler in question has been in service for over a year. The stop valve of the turbine is kept open all the time, irrespective of the load, the pressure at the turbine inlet adjusting itself automatically to such a value as is necessary to force the steam flow through the turbine according to the load. The changes of pressure and load are shown by the charts in Fig. 11. The load was several times suddenly reduced from 24 tons per hour to 10 tons, and afterwards brought back to the original value. Under these conditions the pressure dropped from 2 000 lb. to a minimum of 700 lb. per sq. in. and rose again as the load increased. In the upper left-hand corner of the figure the superheating is shown; this remained practically constant during the whole time. The curves on the right show the pressure and temperature in the back-pressure system, which values also remained constant.

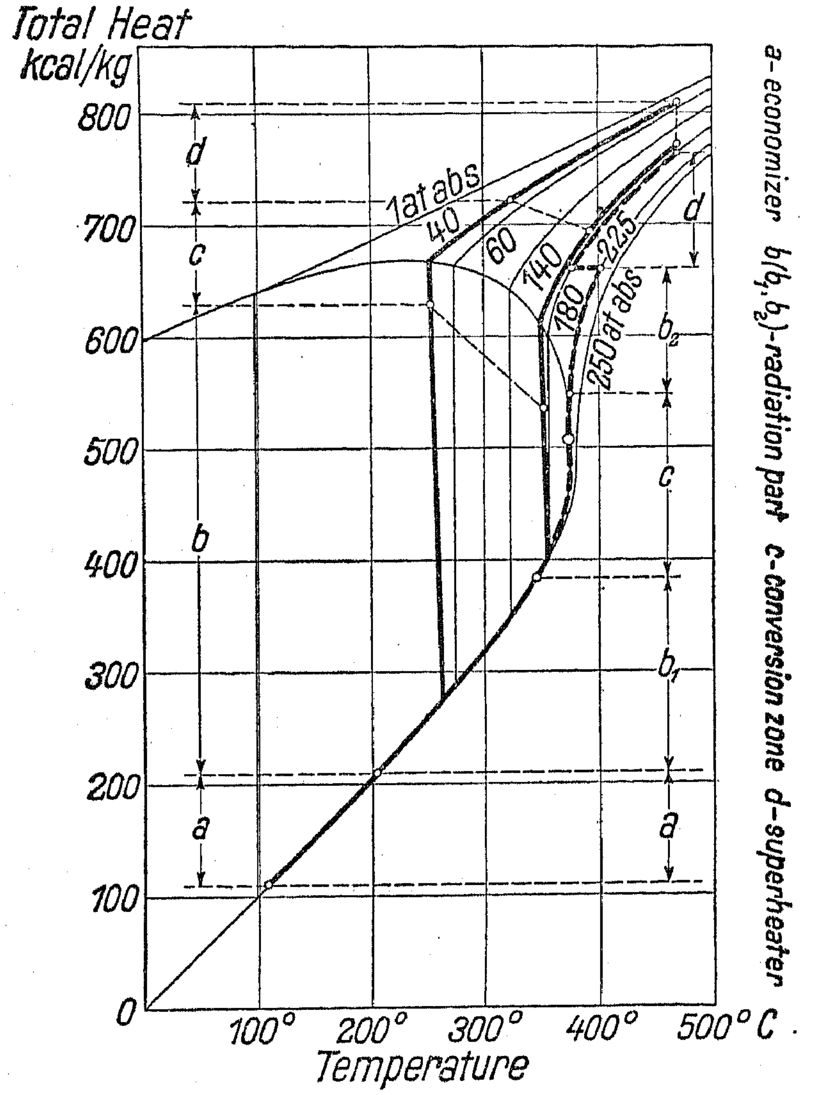
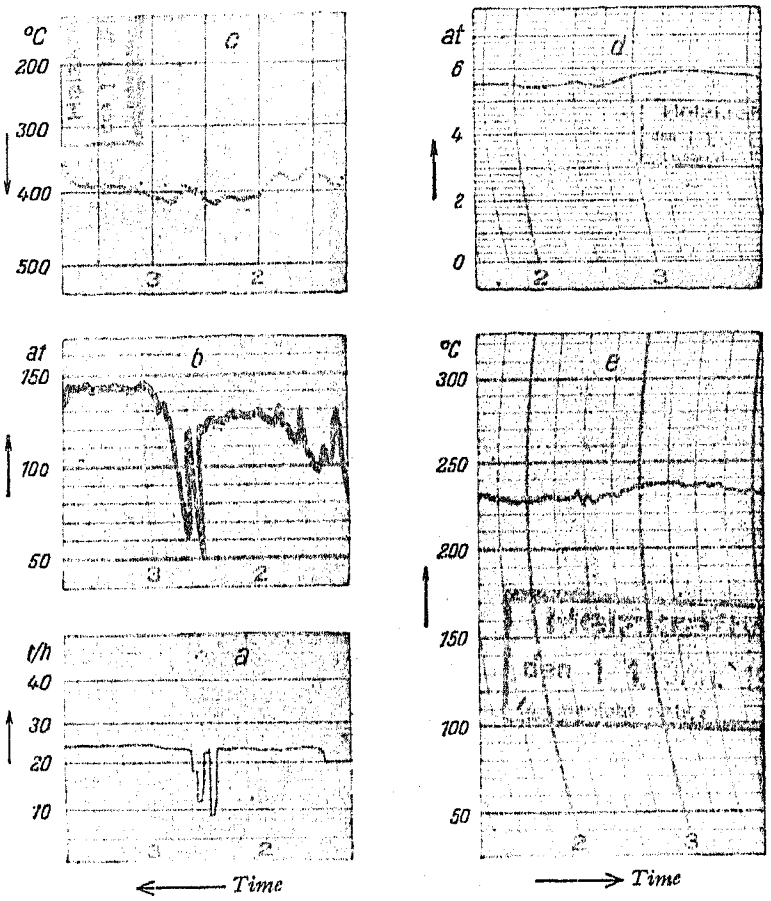


FIG. 10.—Total-heat/temperature diagram for steam. Benson process for critical pressure and sub-critical (variable) pressures.



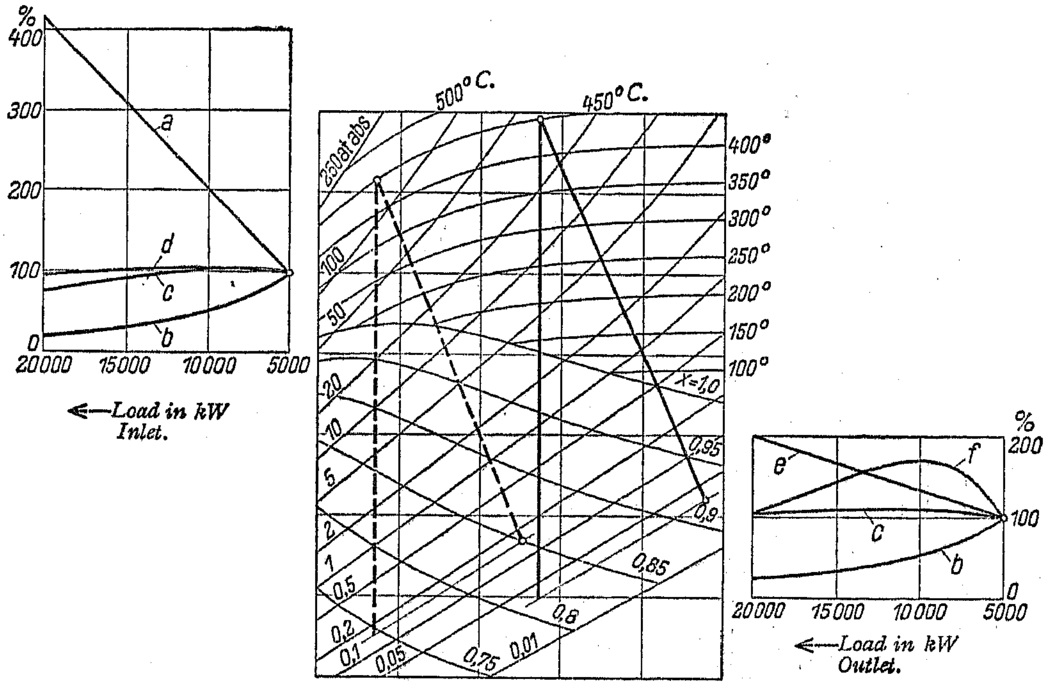
a = steam flow, t/h, b = pressure at turbine inlet, c = temperature at turbine inlet, d = pressure of back-pressure mains, e = temperature in back-pressure mains.

FIG. 11.—Test on the power and heating plant of the Gartenfeld Cable Works, 11th January, 1933.

The possibility of operation at varying pressure can be utilized to particular advantage in power stations operating with fluctuating loads, especially where considerable peaks have to be met. In such cases the turbine is designed to take the most frequently occurring base-load at the lowest economical pressure and, when the peak loads come on, the steam pressure is correspondingly raised so that the weight of the steam passing through the turbine is similarly increased: thus the volume of steam passing through the turbine remains practically constant, since at constant inlet temperature the specific volume is approximately inversely proportional to the pressure.

If, for instance, a condensing turbine is designed for 500 lb. per sq. in. (850° F.) and a good vacuum, approximately 4·5 times the weight of steam can be passed through the turbine, without altering the position of the stop valve, by raising the pressure to 2 000 lb. per sq. in. Of course it would not be possible to utilize fully the available vacuum in the last stages of the turbine. If, however, a condensing plant, liberally designed for 500 lb. per sq. in., is retained, then the power developed in the last stages will remain approximately the same although the vacuum will be somewhat reduced. In

Fig. 12 the limiting cases of the lowest load at 500 lb. per sq. in. and of the highest load at 2 000 lb. per sq. in. are shown in the Mollier diagram. From this it will be seen that both the adiabatic and the useful heat-drop remain approximately constant at all loads. Since the total volume is also constant and the Parsons factor of the machine remains practically unchanged, it follows that the thermodynamic efficiency of the machine, and consequently its specific steam consumption, must be constant at all loads. Governor valves are not necessary for the turbine; if it operates in parallel with other machines; overload valves are also superfluous. All that is required is a stop valve, designed for rapid closing, which can be used for throttling in emergencies.



a=total steam flow, b=specific volume of steam, c=total steam volume, d=adiabatic heat drop, e=final moisture, f=exit losses.

FIG. 12.—Mollier diagram for operation with variable pressure, without reheating.

Instead of keeping the stop valve of the turbine fully open all the time, it may sometimes be feasible to keep it somewhat closed under normal conditions so as to have a certain spare pressure for suddenly applied loads.

As an example of a power plant operating at variable pressure, Siemens-Schuckert have evolved a design for a plant to deal with an extreme load such as that illustrated in Fig. 13, assuming a continuous base load of 5 000 kW with peaks up to 20 000 kW.

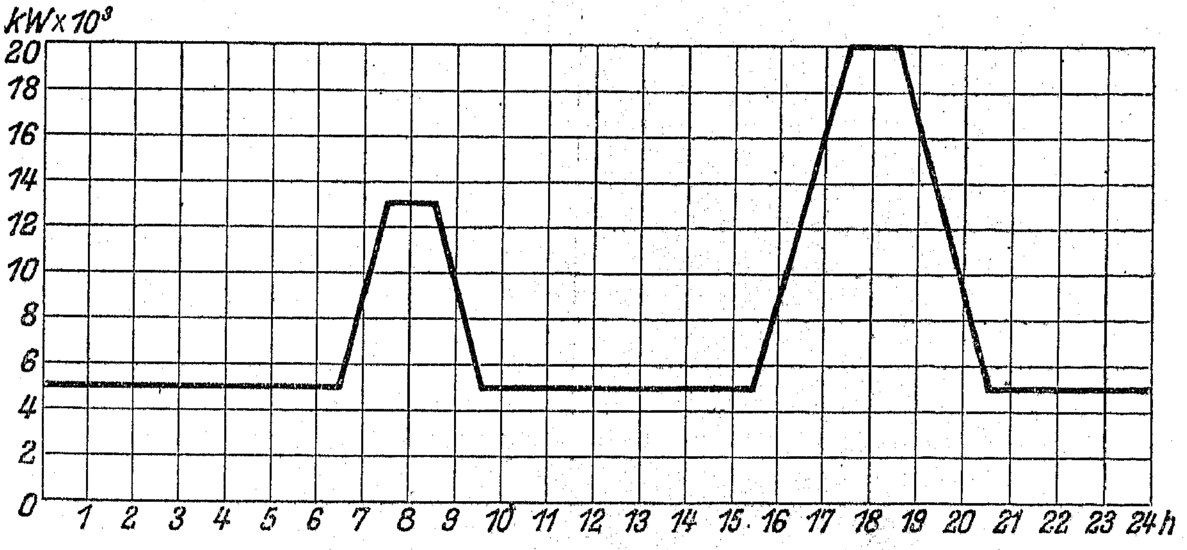


FIG.—13.—Load diagram of peak-load station.

The boiler plant is assumed to comprise two Benson boilers in parallel operation for a normal rated load of about 22 500 lb. per hour each, capable of being increased to about 36 000 lb. per hour each. The boilers are equipped with chain-grate stokers with zoned air supply. For peak loads, pulverized-coal burners are provided, fed from mills operating continuously during the base-load period.

Forced-draught fans supply air to the chain-grate stokers through air preheaters. When the boiler is on overload the temperature of the air rises above 400° F., which temperature, although permissible for pulverized-coal firing, may not be used for grate stoker-firing. On this account part of the cold air is fed from the fan directly to the grate in order to prevent the temperature of the air of combustion under the grate from exceeding 400° F.

For the normal rated load of 5 000 kW the chimney draught suffices. At higher outputs an induced-draught fan is put into operation. The design of the boiler corresponds to that already shown in Fig. 5. The furnace is designed for 45 000 B.Th.U. per cub. ft., i.e. for maximum load. The heating surfaces of the boiler are so dimensioned that a maximum efficiency of more than 84 per cent is obtained at base load, the efficiency at full load dropping to 81 per cent. Up to 5 000 kW the boiler is fed from centrifugal pumps for a pressure of 500 lb. per sq. in. During peak loads a special high-pressure centrifugal pump driven by an auxiliary turbine is brought into operation. As in the case of the main turbine, the auxiliary turbine operates at varying inlet steam pressure and correspondingly varying speed. In addition, the auxiliary turbine drives a generator which supplies current to such of the auxiliaries as must also be operated at varying speed, viz. the feeders for the pulverized-coal burner, the forced-draught and induced-draught fans, and the fan for cooling the generator. The turbine shown in Fig. 14 is of the simple radial-flow Siemens type for the high-pressure cylinder, connected to a low-pressure cylinder of the axial-flow type. This turbine unit will have an efficiency of 77 per cent at 5 000 kW, and 75·5 per cent at 20 000 kW output.

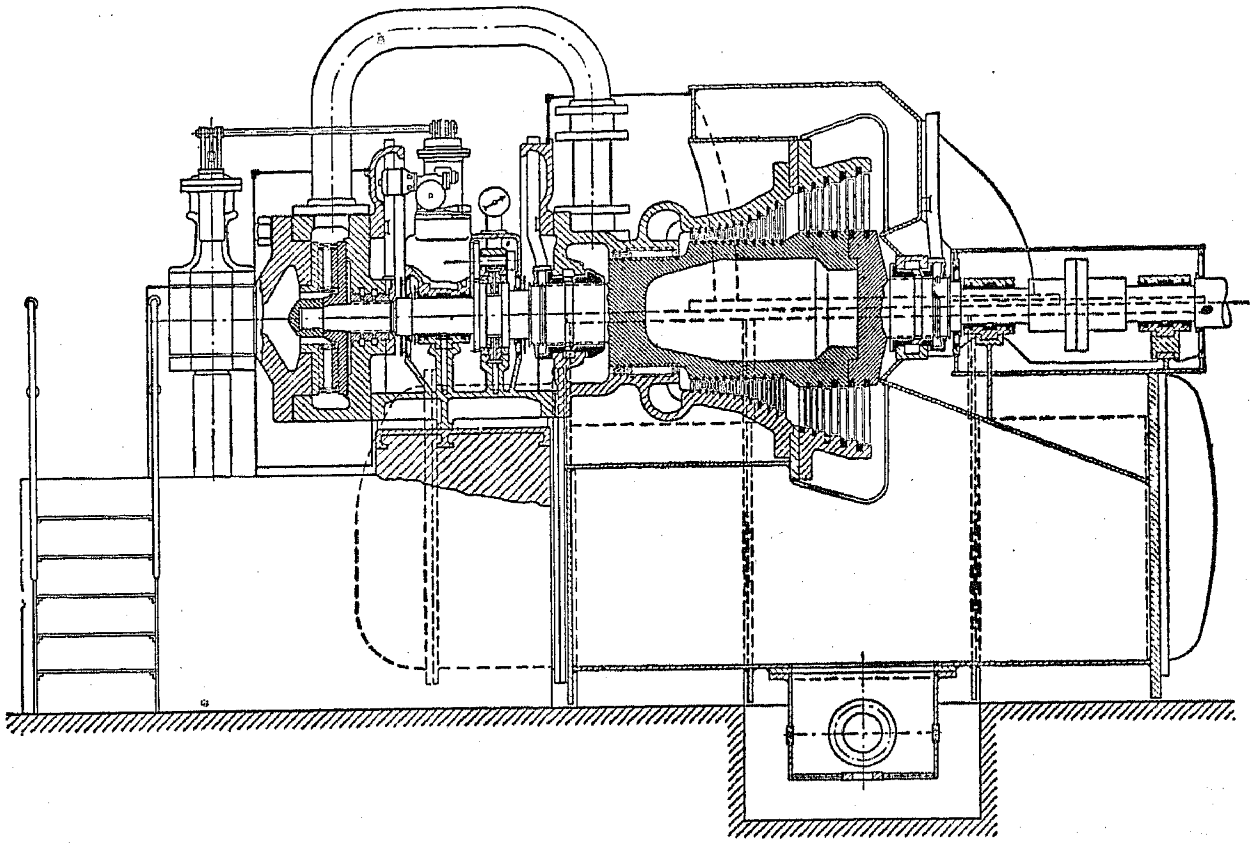
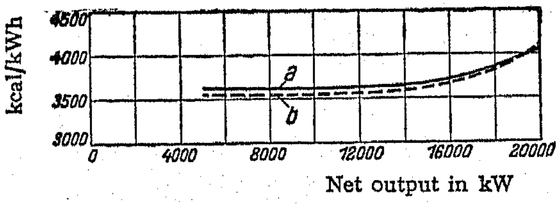


FIG. 14.—Section through single-storey turbine for peak-load station.

Whilst the turbine is actually a standard 5 000-kW machine with a casing designed for a pressure of 2 000 lb. per sq. in., the generator must be designed to deal with the full peak load of 20 000 kW. It is, however, provided with forced ventilation in order to enable the machine to operate at a good efficiency at the lower load of 5 000 kW; its efficiency is 96·5 per cent at 5 000 kW and 95 per cent at full load (20 000 kW).

The heat consumption of a power station designed on these lines for operation with variable pressure—referred to the net kWh—is plotted in Fig. 15. From the curve it will be seen that the heat consumption remains practically constant up to 15 000 kW, and only increases slightly beyond that. In Fig. 16 the heat consumption is plotted above the load diagram on which the design of the plant is based, and from this the mean value of the heat consumption is calculated. For the sake of comparison, the heat consumption is also shown, if based on the same load diagram, but with the inlet pressure of 350 lb. per sq. in. at 750° F. at the turbine valve assumed to be constant.



a=without reheating, b=with reheating.

FIG. 15.—Heat consumption as a function of the load, at peak-load station.

The total cost of the plant, assuming normal foundations and provision of full stand-by in the boiler house for the base load as well as of reserves for sensitive parts of the plant for the peak load, is in the region of the following amounts,* which are based on tenders received in the summer of 1933:—

Mechanical part	£112 143
Electrical part	£6 786
Buildings	£31 071
	£150 000

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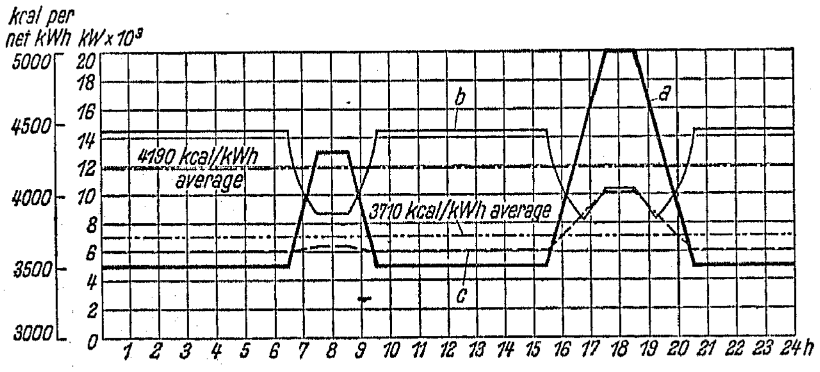
* Calculated on the basis of 14 reichsmarks to the £.

Referred to the peak load of 20 000 kW, the cost per net kW is therefore £7·5.

The example dealt with above indicated the advantages to be obtained from operation at sudden fluctuating pressures in a stationary plant. For warships the conditions are similar. At cruising speed the fuel consumption must be as low as possible, whereas for temporary maximum speed amounting to a multiple of the cruising speed the quantity of fuel consumed is of minor importance. The greater output is simply obtained by increasing the pressure. If for cruising purposes a relatively low pressure of 300 lb. per sq. in. is regarded as sufficient, the maximum power output may be increased to 10 times that at cruising speed by raising the pressure. At the same time the fuel consumption will be less than in plants operating at constant speed.

With merchant vessels matters are different, in that a uniform speed is generally required. For temporary overload, however, as well as for manœuvring in ports and estuaries, a variation of the boiler pressure offers the most economic means of meeting all required variations in the ship's speed. The chief operating advantage of this method is that the steam temperatures in all the stages of the turbine remain practically constant at all loads, even the most extreme, and rapid alterations of the load are without danger to the turbine. The saving in space and weight due to the complete absence of drums and to the small quantity of water contained in the boiler, render the Benson boiler particularly suitable for application to marine purposes, especially when operating with increased flue-gas velocities and a correspondingly improved heat transfer.



a=load, b=heat consumption at constant pressure (25 atm. 395° C) c=heat consumption at variable pressure.

FIG. 16.—Load diagram and heat consumption at peak-load station.

In industrial power plants with condensing equipment, variable-pressure operation can be applied in the manner described above, and the regular daily or seasonal fluctuations of load can be readily dealt with.

The advantage of the Benson boiler in bleeder and back-pressure installations lies in the fact that the live steam pressure can be chosen to correspond to the steam volume to be dealt with in the turbine and not to be higher than necessary to obtain the best turbine efficiency. It is also possible to choose the thickness of the walls of the tubes so liberally that in the event of the extension of the plant the same boiler may be run at a higher pressure. Operation at variable pressure may also be adopted in cases where, in a combined power and thermal station, the amount of steam for thermal purposes would not suffice to enable a back-pressure turbine to deal with any peak loads which might come on to the power system.

This line of thought can be elucidated by an examination of the Mollier diagram (Fig. 17). ABF represents a typical diagram for a back-pressure turbine with an inlet pressure of 400 lb. per sq. in., 625° F., and a back pressure of 60 lb. per sq. in. (abs.), 300° F. If the maximum quantity of steam with which this turbine can deal is no longer sufficient to generate the electrical power required, as well as to supply the steam for the thermal work, it is possible to increase the output by about 30 per cent as compared with the previous output at low pressure, with the same quantity of steam, by raising the inlet pressure to 1 400 lb. per sq. in. and superheating to 800° F., as shown in the diagram. In many cases, therefore, in which hitherto a condensing bleeder turbine had to be installed, a back-pressure turbine with variable inlet pressure can be used.

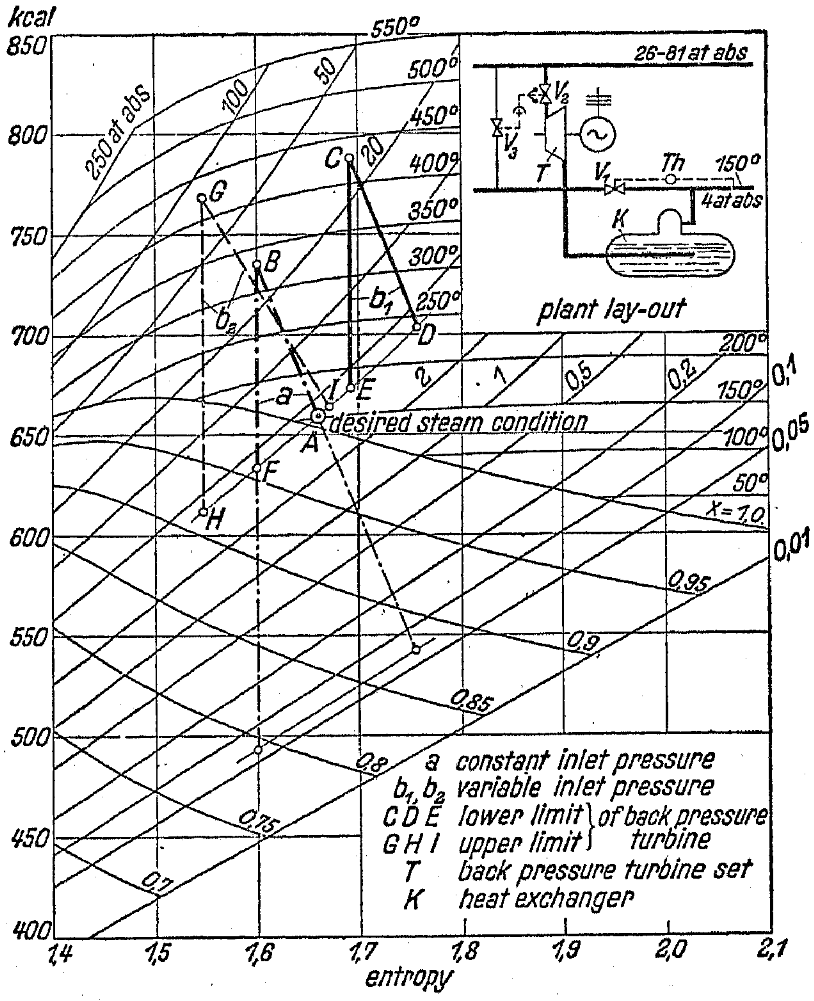


FIG. 17.—Mollier diagram for steam comparison between normal bleeder turbine and back-pressure turbine with variable inlet pressure.

The Benson boiler with variable pressure can also be advantageously used in thermal stations for municipal heat supply. Depending on the heat demand, a definite pressure must be maintained at the outlying points of the pipe network, the pressure being indicated in the power station by means of remote-indicating pressure gauges. The back pressure of the turbine will vary correspondingly, and with open stop-valve the steam condition will automatically adjust itself to operation of the turbine at the best efficiency for any given quantity of steam that may be passing through the machine. If in the course of time the number of consumers increases, the costly work of enlarging the pipe mains is not necessary. While the pressure at the end of the pipe system remains unchanged, the back pressure of the turbine increases, the inlet pressure rises, and the output increases approximately in proportion to the weight of the steam passing through. In the foregoing, only a few examples are given of the many ways in which the operation at variable pressure affects the working of power plants. According to Gleichmann, the advantages and possibilities of the application of this new development of the Benson boiler may be summarized as follows:

(1) Condensing base-load stations, back-pressure plants, and bleeder plants, with but slightly varying loads, as well as merchant ships, will be designed for operation with constant pressure, the value of which can be chosen with a view to low costs and high thermal efficiency, the upper limit of the pressure being the critical pressure.

(2) Stationary plants with widely variable load (peak-load stations), warships, and locomotives, will be operated at pressures varying with the load, by which means a simple and inexpensive turbine and an approximately constant thermal efficiency at all loads are obtained.

(3) Generating stations, industrial plants delivering steam for power process-work, and thermal stations, can be readily designed from the outset so that a future increase in output may be obtained later by raising the pressure according to the larger quantity of steam to be passed through the turbine, in which case the turbine and piping can be adapted to the new conditions at small expense.

It may well be said that the Benson boiler in its present state of development represents one of the simplest and most adaptable boiler designs for all purposes.

DISCUSSION AT A JOINT MEETING OF THE INSTITUTION AND THE INSTITUTE OF FUEL, 15TH FEBRUARY, 1934.

Mr. T. Roles: The Benson boiler was conceived in England and born at Willans works, Rugby. I had the privilege of seeing the original plant, by means of which it was demonstrated that steam could be generated at the critical pressure and could be utilized at that pressure. The idea was subsequently taken to Germany and developed by Messrs. Siemens-Schuckert. The author puts forward the proposition that the Benson boiler, which was originally designed to work at critical pressure, has now been proved to be suitable, by the making of certain modifications in its design, for working at sub-critical pressures. It would have been easier to discuss this question had the paper contained some information as to the results attained by the use of the boiler as it at present exists. My experience at Bradford shows that the cross-drum marine type of boiler is quite suitable for working at a pressure of 1 100 lb. per sq. in.; that little or no more trouble is met with in the working of that boiler than with others working at considerably lower pressures; and that there is no need for the adoption of forced circulation. I regard the drum as an advantage rather than otherwise, and should prefer to have more water stored in the boiler rather than less. At Boston, boilers of the cross-drum marine type are being used for pressures up to 1 400 lb. per sq. in., and at Milwaukee the Stirling type of boiler is employed up to the same pressure. In other parts of America boilers of more or less usual design, fitted with drums, are being used for pressures up to 1 800 lb. per sq. in., the Ladd type of boiler being so used. Turning to the question of efficiency, it is well known that the curve of increase of efficiency due to increase of pressure rises fairly steeply up to 600 lb. per sq. in. From 600 to 800 lb. per sq. in. there is a slight flattening, and from 800 to 1 200 lb. per sq. in. the curve begins to flatten quickly, while over the latter figure it is fairly flat. Having regard to this, and to the fact that boilers of the ordinary type can operate up to 1 800 lb. per sq. in., some very good reasons must be put forward to justify the adoption of a new design such as the Benson. I think the reasons which would have to be given can be summarized as follows: (1) The efficiency of the Benson boiler should be at least as high as that of other types. (2) It should have quite as low costs in regard to repairs and maintenance. (3) It should have a low capital cost. Page 167 of the paper shows clearly that the efficiency of the Benson boiler is no better than that of boilers of more usual design. No figures are given with regard to the cost of repairs and maintenance, and I think it safe to assume that such figures would not be likely to be better than those in respect of boilers of the well-known types. The capital cost for a complete power station, however, namely 105 reichsmarks per kW, is both remarkable and attractive. It would be interesting to know just what is included in the tenders mentioned in the paper; if anything like a full power-station equipment is obtainable at such a price per kW, the scheme put forward by the author is well worth attention, despite its slightly lower efficiency and possibly higher maintenance costs. It is mentioned on page 161 that the burning-out of tubes is caused by the precipitation of salts in those parts of the tubes where the water changes into steam, but on page 163 it is stated that the only time precipitation of the salts takes place is when superheating commences. Which of these statements is correct? In the Benson boiler, which has no drum, probably superheating commences almost immediately the water passes into steam. On the other hand, in a boiler with a drum the saturated steam may have to travel some distance to the superheater before it commences to be superheated. I assume that in the latter case the salts would be precipitated in the superheater and not in the drum. In the Bradford plant, trouble has been experienced through the burning-out of tubes in the first pass of the superheater, and it has been suggested by the chemists that this is probably due to the precipitation of salts causing over-heating of the tubes. With the type of superheater such as is fixed in the cross-drum marine-type boiler we cannot take the steps which the author states are being taken with the Benson boiler, and wash the superheater out while the boiler is working. I should be interested to know whether the author's conclusion with regard to the point of maximum precipitation is based on plant inspection or on temperature measurements in the conversion zone. What does he mean by "pure feed water" for the purpose of the Benson boiler? Condensed water can be taken to represent water with a high degree of purity, but it is slightly acid and necessitates the addition of a reagent such as caustic soda or phosphates to render it alkaline. On the other hand, distilled water contains more solids unless multiple-effect evaporators are used. The water mentioned by the author could not have been pure, because precipitation took place. In conclusion, I should like to pay a tribute to the courage and enterprise shown by Messrs. Siemens-Schuckert in taking up the development of the Benson boiler, and to the tenacity displayed by the firm in making of it a commercial success in spite of the many difficulties which must have been encountered and the heavy expense involved.

Mr. A. G. Bugden: In view of the fact that the Benson boiler was patented in the names of Mr. Wallis and myself, in this country, and that I have been associated with Dr. Benson for 2½ years, it may be interesting if I make a few comments on the original Benson boiler. Mr. Roles is not quite correct in his statement with regard to the original sponsors of the Benson boiler. Dr. Benson commenced his work in this country early in 1922, and probably did some preliminary work in 1921, but until 1922 practically nothing was done with regard to designing and it was a few British people who put up the money for these early experiments. With regard to the burning-out of the tubes mentioned in the paper, the original boiler ran very well for many weeks, but one day, during the tests, the reading of the pressure gauge on the superheater suddenly dropped to zero. Few of the staff realized that anything was wrong until a man reported that steam was being emitted from the top of the chimney. A tube had split longitudinally, owing to a bad weld on the part of the manufacturers. It was repaired, and no further trouble was experienced. I mention this in order to emphasize the point that whilst the Benson boiler worked at 3 500 lb. per sq. in. it was entirely safe. In the original Benson boiler the tubes were in coil formation, there being six coils co-axially arranged in parallel; the superheater tubes were of 40 mm outside diameter and 20 mm bore, and the generator tubes 30 mm outside by 20 mm bore. The main steam pipe for conveying steam to the turbine was only of 1¾ in. bore, and this conveyed sufficient steam for about 800 h.p. of plant. The outside diameter of the pipe was 2⅝ in. It was impossible to induce anybody in this country to make the coils, which therefore had to be purchased from Germany. The short length of steam pipe between the boiler and the turbine, however, was manufactured in this country. Considerable expenditure had to be incurred without any tangible data being obtained to work upon with regard to the details of design. To indicate how much in the dark we were I would mention that in designing the superheater on the basis of the calculated surface, according to the usual methods, the figure obtained was considered low and it was therefore increased by 100 per cent. In the tests, however, the exact required result was obtained. The Benson boiler is essentially a base-load boiler, and the first cost is obviously high. The boiler at Rugby was hand-controlled, in the early stages at any rate. A man was in attendance at the control between the superheater and generator the whole time. Instruments were subsequently added to give some degree of automatic control, but when an endeavour was made to modify the load, owing to the time-lag, hunting occurred. For marine work the scope of the Benson boiler seems rather limited. I understand that duplicate plant was installed on the S.S. "Uckermark." At Rugby an auxiliary boiler was installed to condense steam and so produce fairly pure feed water. No trouble arose from the burning-out of tubes on that boiler. According to the paper, the modifications which have been introduced by Messrs. Siemens-Schuckert have rendered the boiler a forced-circulation boiler, similar to one or two other types now on the market. Such a design is beyond the realm of ordinary boiler-making and is a task for tube makers. With regard to operation, everything depends on the continuous and satisfactory working of the boiler feed-pump. I consider that the effect of the Benson boiler on present practice will be slow so far as the scheme outlined by the author is concerned. Engineers will watch with great interest, however, the performance and life of the Benson boilers now in operation at the Gartenfeld Cable Works and at Langerbrugge. At the present time, 12 years after the original work was started, there are only some five Benson boilers in operation.

Mr. W. M. Selvey: There have been few difficulties in running boilers at about half critical pressure, but among these one of the most persistent is the appearance on the turbine blades of deposits of the soluble salts from the feed water. Attempts are now being made to reduce the proportion of impurities to as low a figure as 7 parts per million, i.e. 7 milligrams per litre. This seems to be the lower limit in Fig. 1, which appears to refer to experiments carried out at the critical pressure. The new factor brought into the field appears to be that at the critical point the soluble salts can be made to adhere almost entirely to the heating surfaces. How completely they adhere, in a large working boiler, is not stated in the paper; information on this point would be of particular interest. Another matter of interest is whether at or about the region of deposit the salts have any action on the metal. The very soluble salts, namely sodium sulphate, sodium carbonate, and sodium phosphate, are, of course, re-dissolvable. Would salts of the alkaline earths of calcium and magnesium precipitate to some extent before? Natural circulation clearly depends on the difference of density of water and a "water-steam" mechanical mixture. As the density of steam approaches that of water this motive for circulation disappears, and forced circulation is essential. Being thus freed from the main considerations which apply to ordinary boilers, the drum disappears and the heat-storage capacity also largely disappears, except so far as heat is stored in the superheater tubes and casing. One step further and the boiler becomes a machine with governing on the feed inlet instead of on the turbine stop-valve. This brings us to an entirely new technique, in which pressure may be made incidental to output. The final suggestion is an elaboration of the aspect of peak-load plants discussed at the World Power Conference, Berlin. The output of the turbine is proportional to the pressure P_1 at the first set of nozzles. If a turbine is designed for maximum economy at a low value of P_1 (one-quarter load is suggested in Fig. 14, and a little over half load in Fig. 17), then the output will be proportional to P_1; but the steam will be under-expanded at the back end, being limited by the critical velocity in the last effective set of nozzles. Two factors remain to be decided, namely the capacity of the alternator and the design vacuum for the condenser. If these are to be full-scale there is little saving to be effected; and if not, then the machine becomes very special and is pinned down to its particular kind of life for all time, however circumstances alter. I am not sure, therefore, whether in a large interconnected system with many homogeneous units which are started and stopped according to programme, the peak-load type of boiler will have a wide influence on the development of power stations. The development of electrical storage water-heating systems to any considerable extent would greatly limit the desire for such special machines. I am more interested, therefore, in the general high-pressure case, and its development in various countries has now definitely secured it as a permanent feature of power production. The resulting economy of the limiting pressure as related, say, to a pressure of 650 lb. per sq. in., is apparently not highly attractive to the engineers of large power schemes at the moment, but the possibility of far higher utilization of active material is very attractive. An analogy is the difference in space occupied and material used by the low-speed and high-speed Diesel engines. This should ultimately be reflected not only in the price of the boiler, but also in a lower price for the housing structure, now becoming a serious item in the total capital cost.

Mr. W. S. Burge: It is rather surprising that the paper does not include anything in the nature of an introduction to the subject, dealing with the possible or expected efficiency gain due to operating at critical conditions. An examination of the subject from this point of view must be based on the fundamental maximum cycle efficiency that can be attained. It is interesting to make a comparison on this basis between (*a*) the steam cycle used at Langerbrugge, where a Benson plant is running, generating steam at critical conditions, (*b*) a typical 1 200-lb. per sq. in. installation, employing reheating, of which there are many examples in the United States, and (*c*) British practice in the use of steam at 650 lb. per sq. in., 850° F., and 29 in. vacuum, without reheating. Taking then the maximum cycle efficiency on these three classes of plant, the Langerbrugge plant has an efficiency of 44·6 per cent. The American 1 200-lb. per sq. in. plant, as used by the California Edison Co. at San Francisco, has a maximum efficiency of 42·7 per cent. Our British plants for 650 lb. per sq. in., 850° F., and 29 in. vacuum, have a maximum cycle efficiency of 39·65 per cent. Thus the Benson plant shows a fundamental gain of 4·45 per cent as compared with American practice, and 12·47 per cent as compared with the most recent British practice. The maximum cycle efficiency, however, although it should be the basis for all comparisons, must be corrected by the practical plant-item efficiencies realized up to date, and when this is done there appears to be very little hope at present of the efficiency of the Benson plant exceeding, or even equalling, that being attained with our modern British steam conditions. Consider for a moment the actual conditions on the Langerbrugge plant. In order to raise steam at 3 200 lb. per sq. in. the feed pumps have to operate against a pressure of 4 250 lb. per sq. in., there being a pressure drop through the boiler proper of 1 050 lb. per sq. in. and a pressure drop in the super-heater of 356 lb. per sq. in. Therefore, although the boiler itself is giving steam at the critical conditions of 3 200 lb. per sq. in., 706° F., the steam delivered to the turbine is at 2 844 lb. per sq. in., 840° F. An examination of the turbine-condition curve for the high-pressure turbine shows that it is operating at an efficiency of not more than 50 per cent, and possibly rather less, and with this efficiency half the electrical output from the high-pressure turbine goes to drive the boiler feed-pumps. When the Benson installation is running at about quarter load but at full pressure, the power for driving the feed pumps is in excess of the output derived from the high-pressure turbine. It is evident, then, that in the present state of the art the very small additional heat-drop gained by the use of steam at critical conditions cannot result in any efficiency gain as compared with the use of steam at lower pressures. On the Langerbrugge plant the heat drop through the high-pressure turbine is only 121 B.Th.U. The author strongly recommends a variable-pressure method of operation, and I am inclined to think that this recommendation is more a matter of expediency on account of feed-pump losses than any belief in an inherent gain due to variable-pressure operation. I am quite prepared to believe, however, that in the circumstances variable-pressure operation may present the best solution for certain classes of load curves if steam is to be generated at critical conditions. From an efficiency point of view there is, I think, some considerable advantage in the use of a drumless boiler such as that developed by Benson and Messrs. Sulzer. There is a growing opinion that when steam is raised at 1 200 to 1 400 lb. per sq. in. the value of drum storage has decreased to such an extent as to justify the question whether the cost of the drums is worth while. In a boiler of the Benson type there is no heat storage, and the operation of the boiler depends entirely upon perfect regulation of fuel, air, and water admission. If such regulation can be made reliable, it seems evident that a big reduction in cost and weight can be effected, and if such is the case the development work which is being carried out on the Continent in connection with this type of boiler may prove in the near future to be of considerable value. I think we are approaching a parting of the ways between the present conventional type of boiler with heat storage in the form of water drums and fuel bed, and this new type of flash boiler without any heat storage but employing perfect regulation of fuel, air, and water as required from moment to moment.

Mr. N. C. Bridge: Mr. Roles suggested that the paper might have given us more information about the construction and operation of the boiler, but that is more a matter for the mechanical engineer, and the author has quite rightly, I think, under the circumstances, confined his paper to "The Influence of the Benson Boiler on the Development of Power Stations." This influence is, however, at the moment, a little difficult to see. The power-station designers of this country, at any rate, are not, I think, particularly impressed with the flash type of boiler, though I am quite certain that they will watch with sympathetic interest the performance of the Benson boiler and boilers of that type at Langerbrugge and other places. There is a reference in the paper to the throttling of the steam which is necessary before it can be used in the turbine. I should like to ask the author whether he can give us the thermodynamic efficiency of this throttling process. There seems to be a loss of total heat, because after the steam is throttled it has to be re-superheated to the previous temperature. Is that offset in any way by a gain in entropy, or what is the loss? With reference to governing on the fuel, already referred to by several speakers, this, in effect, is a transfer of function and one which brings us nearer to the internal-combustion engine. It is possible only if there is no thermal storage whatever between the boiler and the turbine; there must be no lag. A point which I do not see mentioned in the paper is the effect of the high initial pressure of the steam on the position of the dew-point in the turbine, more particularly in connection with the suggested variable-pressure system. How does the dew-point move up and down the turbine in that system as compared with the position under the constant-pressure system? Or, alternatively, how does the dryness factor vary? The author suggests that with this variable-pressure system the auxiliaries should be operated from what is apparently to be a variable-frequency auxiliary set. Now, what would the people of this country think if, after having spent enormous sums of money in standardizing the frequency at 50 cycles per sec., we were to vary the frequency in our own power stations?

Mr. R. P. Wallis: I have listened to the paper with particular interest for two reasons: firstly because I was associated with the Benson Engineering Co. in 1922 and 1923 in the design of the first Benson steam generator, and secondly because, owing to the kindness of Messrs. Siemens-Schuckert, I have been enabled to visit the Gartenfeld Cable Works and see the two steam generators in operation there. I have also seen the old Borsig boiler which was used in the experimental work carried out at the works of Messrs. Siemens-Schuckert, and have inspected the experimental plant at Charlottenberg. In 1922, when the experimental generator was first designed, our knowledge of the working conditions at the critical pressure was very scanty. As Mr. Bugden has pointed out, much of the designing work had to be regarded as experimental, for although there was available a great deal of valuable information in regard to low pressure, very little was known about the properties of superheated steam at 3 200 lb. per sq. in. Again, the art of welding was in quite a different position from that which it occupies to-day. At that time it was regarded as a bold step to arrange for all the joints in the heating elements to be welded. All the tubes exposed to the furnace temperature were of the same diameter, and the headers were kept outside the furnace. It is of interest to compare the original steam generator with the latest product, the result of 12 years of development and patient research by Messrs. Siemens-Schuckert. The Benson steam generator at Rugby consisted of a refractory cylindrical combustion-chamber with four oil burners at the bottom. The combustion chamber was of sufficient volume to ensure complete combustion of the fuel before the gases came in contact with any of the generator or superheater elements. The generator elements were composed of six helical coils, installed between the outside of the cylindrical combustion chamber and the firebrick lining of the casing. Above the generator coils were arranged the superheater coils, of similar construction but slightly larger diameter. The generator coils were of 2 cm inside diameter and 3 cm outside diameter, and it is interesting to note that Messrs. Siemens-Schuckert still use this diameter and thickness of tube. The Rugby superheater tubes were of 4 cm outside diameter and 2 cm bore. In later designs there will be a tendency to reduce the thickness of the superheater tubes in order to minimize the temperature stresses. The combustion chamber of the first steam generator installed at the Gartenfeld Cable Works was cylindrical in form; that of the second Gartenfeld generator was cylindrical at the top and square in section at the bottom. The combustion chamber installed in the S.S. "Uckermark" departed from the cylindrical form, being almost rectangular in cross-section. The heating elements of the Rugby generator were helical in form, and the water passed through them in parallel. In the first generator at the Gartenfeld Cable Works the tubes were straight and vertical. This generator was fired with pulverized coal from four burners, equally spaced, at the top. On full load all the burners were in operation and the generator operated successfully. The method of reducing the load was to reduce successively the number of burners in operation. Thus on quarter load only one burner would be functioning. Under these conditions the water in the vertical generator elements close to the pulverized-coal burner in operation, became much more rapidly heated than the water in the elements remote from that burner, causing water-hammer and unsatisfactory working. The vertical elements of this generator were eventually removed and replaced by helical coils similar to those of the Rugby generator. The heating elements of the second Gartenfeld generator and of the original Langerbrugge installation consisted of horizontal coils, but the author informs us that at Langerbrugge trouble has been experienced due to the expansion of such large coils and the consequent displacement of the tubes. These coils have now been replaced with straight tube elements. What provision is being made to prevent the same difficulty as occurred with the straight tubes in the first Gartenfeld generator? With regard to the general arrangement of the heating surface so as to obtain contra-flow conditions, in the Rugby generator the gases passed down and the water up. Even with forced circulation this appears to have a very distinct advantage over the reverse method. With this method the natural circulation of the water assists the forced circulation, and the steam is withdrawn from the top. In most of the Siemens-Schuckert boilers this principle has been retained, although the effect is obtained in a rather different way, the pulverized-fuel jets and oil burners being installed at the top of the boiler. This is interesting because when the design of the first generator was being considered in 1922 the question of putting the oil-burning equipment on the top was considered, but the idea was abandoned owing to the weight of this equipment in relation to the size of the generator. Passing to the question of the position of the superheater and the control of the temperature of the superheated steam, it is interesting to read that it took years of research work to determine the correct position in which the transition from water to steam should take place. The superheater was placed at the top mainly on theoretical grounds: this is the portion of the plant in which the heat has to be added to the working fluid at maximum temperature. The superheater was therefore placed in the first pass, i.e. in the hottest portion of the gas. The original conception of the damper control was the idea of placing two fire tiles at right angles, recessing one into the other. In normal operation the gases would pass over the whole of the superheater tubes first and then down over the generator tubes. When the damper was reversed it cut off the flow of gas to the top portion of the superheater tubes, thus varying the degree of superheat. As the design of the whole generator evolved, this damper control became very complicated, and nobody was surprised when under test conditions the dampers fused in one fixed position and had eventually to be entirely removed. The author refers to the suitability of the Benson boiler for marine purposes, "especially when operating with increased flue-gas velocities." Has he considered the use of gilled tubes in preference to plain tubes? At high velocities gilled tubes have several advantages, one of which is that the draught loss for the same heat-transfer is considerably less than with plain tubes. Perhaps the author would say something about the policy with regard to the manufacture and sale of Benson boilers in countries other than Germany.

Mr. C. W. Pratt: The author informs us that simply by raising the boiler pressure the turbine load can be correspondingly increased, and that from a turbine installed in the first place for a given duty a greater output can in this way be obtained at some later date. It is not made clear, however, that no advantage is gained in respect to the boiler plant, for it is necessary to put in a larger boiler sufficient for the greater duty expected, and the auxiliary equipment, induced- and forced-draught fans, etc., must also be of the capacity necessary to deal with the increased output; thus entailing a larger capital outlay in the first place on the boiler plant. Development of the Benson boiler has been necessarily slow, but I think that even the drum type of boiler will gradually reach the same stage as the Benson type. As boiler pressures are increased, natural circulation becomes more difficult, but this does not prevent some kind of booster pump being put into the water circulating system to provide a forced circulation in the boiler proper, and there is a possibility of orthodox designs developing and coming into line in this respect.

Mr. W. Hamilton Martin (*communicated*): The author mentions that the Benson boiler is applicable to the widely varying loads met with in locomotive work. Would a relatively low sub-critical pressure be employed in such applications? If so, many advantages claimed for the Benson boiler seem also to be offered by such boilers as those used by Messrs. Henschel and Doble,* which are of the single-coil type. Such boilers, which are now being applied to steam-cars, omnibuses, and railroad cars, in sizes from 80 to 400 h.p., should also prove applicable to locomotive work. Steam is generated in these at a pressure of 100 atmospheres, and a superheat temperature of 840–900° C. is employed. In a 1-hour test run of such a railcar the superheat temperature remained constant within 30 deg. F. (approximately within 3 per cent), although the load varied continuously between 10 and 150 h.p. and the steam pressure ranged from 5 to 80 atmospheres. The steam consumption of the compound engine remained very uniform between one-third and full load, the actual value being about $11\frac{1}{2}$ lb. per effective h.p.-hour.* Is the Benson boiler sufficiently developed to supply steam in such smaller quantities and to meet such ever-varying demands as are met with in locomotive service, and would its performance be satisfactory as regards constancy of superheat and instant response to requirements? Experiences with the White steam-car lead one to speculate whether extreme pressure is very important if one can maintain an exceptionally high superheat temperature. The better high-temperature-resisting materials employed for superheater tubes are suitable for use in coil-type boilers having welded tube-joints instead of the screwed muff couplings with which the White boiler was equipped, and should enable much higher superheat temperatures than the 850° F. mentioned by the author to be obtained. The quick response to wide variations in steam demand exhibited by Benson- and Doble-type boilers may make them suitable for driving small high-speed turbines for locomotive use, one of the infinitely-variable fluid transmission systems being employed so as to get the necessary starting torque for moving the train. Is there any specific reason other than suitability of materials why the author takes 850° F. as the steam temperature in the turbine installation described by him? One would like to see temperatures of 1 000° F. and more employed in the Benson boiler. If such temperatures were possible and suitable, arrangements might be made to use the simple coil type, or, for larger powers, the parallel coil type. The coils would be barrel-shaped or even take the form of flat spiral layers. They would be supported in such a way that they could expand freely, and the tube diameter would be kept small so as to ensure high circulating speeds. There should be no fear of salt adhering since the scouring action of the steam would prevent precipitation. I should like to refer to the case of a White steam boiler operated by me in a country situated mainly below sea-level, where often brackish ditch water was used for replenishing the make-up feed and the cylinder oil was turned into a hard black tarry substance by the intense superheat. The four lower coils nearest the burner, which were always white hot and filled with steam, not water, when in operation, were detached and opened up after 7 years' daily operation. The marks of the drawbench on the inner surface of these tubes were still clearly discernible, and they were as clean as if they had just been through a pickling bath. Notwithstanding this, they had sagged between their supporting points on account of the continuous heating and jolting on badly-paved roads. Now that materials,* lubricants, and welding† are available and close superheat control is better understood, it would seem that the continuous-coil-type Benson or Doble boiler should be the one to supply steam at extra-high temperatures rather than extreme pressures. The use of flat tube elements with headers and collectors, and their many expanded connections, increases the cost and complexity of the Benson boiler and will not readily allow definite circulation velocities and extreme superheats to be obtained or maintained. What factor of safety has been allowed for the materials of the boiler tubes of the Langerbrugge and "Uckermark" boilers? What factor of safety will be allowed in the critical-pressure type of the later flat-tube element boilers described in the paper? The question of the speedy removal of the gases of combustion would seem to be the deciding factor in the maximum rating of such boilers as that installed in the S.S. "Uckermark." Draught power thus becomes of paramount importance, and on it depends the amount of fuel which can be supplied to the burners. In conjunction with this, a high circulating speed becomes necessary in the continuous-coil small-bore type, and the power allowed for this gas removal and circulating of feed becomes a matter of most careful estimating if high rating be required. Has any great change been made in the air-heater and economizer surfaces, or the circulating speeds and means for removing the burnt gases, of the "Uckermark" since she came up the Thames for inspection about 1½ years ago? Dr. Goos recently quoted the figure of 91·5 per cent for the efficiency of the Benson boiler. Does this figure relate to the best efficiency of the "Uckermark's" boiler, or to the mean obtained on it when working at critical or sub-critical pressure; or is it to be taken as an average figure for the Benson boiler in coil form, or as now put forward by the author for land or marine work when oil-fired? What may be expected from it when fired by pulverized fuel, coal, or coal-oil fuel? I mention the last type of fuel because it would seem to be particularly suitable for the Benson boiler. The coil can be made in the most suitable shape for abstracting the heat from coal-oil mixtures or colloidal fuels, which give their most intense heat in a zone near the burner. An envelope of tubing could be arranged there of small bore, and consequently high circulating speed, so as to extract a maximum of heat from the burning gases. The Johnson water-tube boiler likewise lends itself well to the formation of the best-shaped combustive chamber to extract the maximum heat from a given fuel. Burners are already existent which will atomize several thousand pounds of fuel per hour perfectly, without any small nozzle constrictions. These burners should consequently be admirably suited for coal-oil mixtures, with which a more local intense heat-transfer would seem possible. They should also enable a high superheat temperature to be attained quickly, and from this point of view are well adapted to peak-load work at maximum economy. Turbines could soon be designed to meet these high-temperature conditions, as they already operate satisfactorily at 1 000° F. The author has opened up new possibilities in boiler work, economic methods of steam supply, and operation of turbines. The boilers which he describes must be made as simple as possible, however, and preferably have a minimum of joints and maximum freedom for expansion, with as high and uniform circulating speeds of water, steam, and hot gases as practicable, if extremely high temperatures are to find successful application.

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* *Transactions of the Institute of Marine Engineers*, 1932, vol. 44, p. 582.

* In regard to the steam consumption of small high-pressure high-superheat engines, see *Transactions of the Institute of Marine Engineers*, 1929, vol. 41, p. 337 also 1934, vol. 46, p. 64.

[The author's reply to this discussion will be found on page 179.]

NORTH-EASTERN CENTRE, AT NEWCASTLE, 12TH FEBRUARY, 1934.

Mr. C. D. Gibb: I think there are many drawbacks to the author's proposed new methods of operating power plants. He refers to the boiler at the Siemens-Schuckert Cable Works having its steaming output suddenly reduced from 24 to 10 tons per hour; but every modern power station has to be designed for a possible variation in steaming output from 100 per cent rating to approximately 10 per cent rating, to provide for the possibility of the station being struck by lightning, or the occurrence of a line or switchgear fault equivalent in effect, when the only load remaining on the boilers would be that due to the turbines running light. The author's diagrams of the Benson boiler indicate chain-grate-stoker firing, and therefore under emergency conditions it is not possible suddenly to stop the heat from combustion, as would be the case were pulverized-coal or oil firing adopted. A boiler provided with steam or water drums has only a limited reserve supply of water in the system, but it nevertheless has some reserve, whereas in boilers of the single- or multiple-tube type having no storage capacity a continuous flow must be arranged for in order to prevent tube-burning. This could probably be done by blowing off steam to the condenser, but English power-station practice would certainly demand some water-storage capacity or other means of enabling the tubes to be safeguarded during emergency conditions. Has some such arrangement been adopted in the boilers under discussion? The turbine at the Siemens-Schuckert Cable Works must obviously have either back-pressure-controlled governor gear or some means of controlling the back-pressure mains, and the charts given in Fig. 11 would appear to be remarkable only for the manner in which the rate of combustion is checked. Presumably this is accomplished not by stoker control but by the cutting-off of either powdered-fuel burners or oil burners. The variation in steam temperature (Fig. 11*c*) which appears to be as much as 50 deg. C., is considerably greater than one would normally expect from other types of boilers. Dealing with the suggestion that the boiler pressure should be raised to enable overloads to be met, perhaps the most striking point is the price quoted for the electrical part of the power station, namely £6 786 for a 20 000-kW alternator. This figure appears to be rather low. Presumably it does not include the outlay on the necessary switchgear, and when such items are included the cost per kW of the plant will not be sensibly different from that of a power station designed on more normal lines, while its efficiency will certainly not be as good. The author states that the turbine unit has an efficiency of 77 per cent at 5 000 kW and of 75·5 per cent at 20 000 kW, but he does not say whether these figures are overall efficiencies. Even assuming that they are overall figures, however, they are much lower than would be obtained with a more simple and straightforward type of plant. The load and heat-consumption diagrams given in Fig. 16 are obviously incorrect; perhaps the author would explain why a unit designed for 350 lb. per sq. in., 750° F., should be roughly 30 per cent less efficient than a unit where the pressure is 500 lb. per sq. in. at 5 000 kW and the whole design obviously a compromise. The throw-away to the condenser due to the fall in vacuum under the high-load condition outlined by the author, is so great that I cannot foresee its general adoption, nor do I consider it to be justified on economic or other grounds. There seems to be no fundamental reason why the Benson boiler should be more suitable for variable-pressure operation than any other type of boiler, except its ability to respond quickly to steam-demand variations; and there is not the slightest doubt that practically any water-tube boiler, suitably adjusted, could give results equal to those obtained with the Benson boiler, when operating over a wide pressure range. The Benson and other types of boilers recently developed on the Continent have to a great extent thrown overboard tradition, but, while this may be a good thing in some cases, tradition is generally founded upon a very substantial basis. For marine work the Benson boiler probably has a definite field, but there seem to be many objections to adopting the Benson type of boiler in power stations. The increase in size of turbine units, together with the interconnecting of power stations generally in this country, have shown the necessity for turbine governor gear to be even more sensitive than had previously been the case. Under fault conditions in a power station it is essential that the unit should continue to run at normal speed after the fault has been cleared, and for this reason governor gear must be placed in the steam lime extremely close to the turbine. If this is not done, the steam stored in the pipes from the boiler to the turbine will be ample to cause the unit to run at excessive speed and result in the closing of emergency valves, thus leaving the operator without a machine available to put back on the line when the fault has been cleared.

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* W. H. MARTIN: *Transactions of the Institute of Marine Engineers*, 1934, vol. 46, p. 27; also *Journal I.E.E.*, 1932, vol. 71, p. 584.

† *Transactions of the Institute of Marine Engineers*, 1933, vol. 45, p. 291.

Mr. W. T. Bottomley: The author is to be congratulated on producing a paper which may be of great importance in the development of the Benson boiler. Before the paper was read the general impression was that the boiler generated steam at the critical pressure, i.e. 200 atmospheres, and since this is too high to allow of the maximum efficiency being obtained—even from a large turbine—there did not appear to be any particular advantage in generating steam at the critical pressure. According to the latest views expressed in the paper, the Benson boiler is capable of generating steam at any pressure from the critical pressure down to a normal value of 300 lb. per sq. in. (20 atmospheres) and less, and I think that this new development completely alters the prospects of the boiler. The main argument in favour of the Benson boiler is that it is cheaper for generating steam at the high pressures required for modern power stations than an ordinary water-tube boiler with a steam drum. So that, assuming satisfactory governing can be obtained, and without claiming any improvement in efficiency, there is a prima facie case for adopting it on the score of cost alone. A turbine which is to be subjected to variable pressures must, however, be made stronger in order to withstand the highest pressure, and will therefore cost more. The author gives the cost of a Benson boiler plant, and I suggest that he should give the corresponding cost of an ordinary boiler plant, and thus show the saving in cost per kW of plant installed due to the adoption of the Benson boiler instead of the drum-type boiler designed for operating at, say, 600 lb. per sq. in. It is doubtful whether claims to improved station efficiencies with the Benson boiler can be substantiated. Fig. 13 shows how it is proposed to deal with a daily load curve by raising the pressure from 500 to 2 000 lb. per sq. in. in order to meet the peak. If the peaks had not been confined to certain hours of the day but had been distributed for short periods over the 24 hours, as, for instance, with a traction load, the author's method of meeting the peak might have been ideal, with satisfactory governing. Nevertheless, the application would have been somewhat limited. Where the peaks are concentrated, however, as shown in Fig. 13, it is usually possible to anticipate them. The normal practice in such cases would be to have, say, four sets running plus one stand-by on the maximum peak, each of 5 000 kW normal load and capable of giving 25 per cent overload at a reduced efficiency, and to run one set for the average load of 5 000 kW. This would be more efficient than the author's scheme because the efficiency of the station would depend almost entirely on the conditions when running at 5 000 kW, and the steaming conditions would be the same in the two cases, namely 500 lb. per sq. in. and maximum temperature. The author's scheme is saddled with the additional heavy losses of a 25 000-kW alternator running at less than quarter full load, and the extra losses on this account would amount to over 4 per cent. His scheme would also necessitate installing at least one extra machine as stand-by. So that, against a normal scheme of, say, five 6 250-kW machines totalling 31 250 kW, or alternatively three 12 500-kW machines totalling 37 000 kW, the author's proposal involves two 25 000-kW machines totalling 50 000 kW; but the condensers for the author's scheme need not be larger than those necessary for dealing with 6 250 kW each. The author says nothing about the governing of the machine, beyond remarking that governing is not necessary. This appears to be a most important point, however, when considering the application of the variable-pressure Benson boiler to power-station operation. A Benson machine should be capable of running in parallel with other existing machines on a system; and since the speed and load of existing machines are controlled by centrifugal governors to keep the frequency constant independently of the load on the system, the governing of the Benson machine must also be controlled by centrifugal governors. I understand that the governing of the load on the machine is done by controlling the speed of the feed pump, and I should be glad if the author would say whether the governing of the feed pump is in any way connected with the centrifugal governors of the turbines. Also, is it possible to achieve the same sensitiveness of governing as is obtained at present in power stations, i.e. giving a permanent rise of 3 per cent in the speed when the full load is tripped off electrically? It is difficult to see how the individual loads of several Benson machines running in parallel at one station are to be controlled either by centrifugal governors or by hand if the feed pumps discharge into a common feed range and the steam from the boilers is fed into a common steam range. It would seem to be necessary to have some sort of throttle governor valve on each machine connected to the governor.

Mr. A. H. Waring: The paper shows that the Benson boiler is now a practical proposition, if the make-up feed water is small in quantity and good in quality. It would, however, be interesting to know whether the author thinks that the Benson boiler could be further developed for industrial service, where the make-up feed water is chemically conditioned water and represents some 30 per cent of the total feed water. His method of slightly increasing the output of the feed pump and then scavenging the various sections of the heating surface in the conversion zone, one at a time, so that the output of steam is unaffected, is ingenious; but would this method be satisfactory for such industrial service as the above, both in regard to preventing the formation of scale on the boiler heating surface and in regard to preventing deposits on the turbine blades? It is stated in the paper that with pure feed water a Benson boiler can run for weeks without any scavenging being necessary. In this case is it not necessary to maintain a certain caustic alkalinity of the feed water entering the boiler, so that corrosion in the boiler may be avoided?

Mr. C. H. G. Hayward: Is it possible, in event of a feed-pump failure, to shut down a stoker-fired Benson boiler quickly enough to prevent damage to the tubes? It took approximately 30 seconds to shut down the Langerbrugge boiler in an emergency of this sort, during which period the tubes were damaged. Does the re-arrangement of the radiation zone overcome the serious problem of burning-out of the tubes? With regard to feed-pump practice, a unit for approximately 100 tons per hour output would presumably require a special pump consuming about 2 500 kW (approximately 25 000 lb. of steam per hour) when working at the critical pressure.

Mr. J. W. Jackson: I should like to know how scavenging of the boiler tubes is carried out while the unit is on load. What steps are taken to prevent scale or other foreign matter entering the turbine and causing serious damage on account of the high velocities at which the steam is used? How are the sections of the boiler scavenged separately? It would appear that by thickening the metal sufficiently it would be possible to prevent damage arising from bursting; but is this an economic way of dealing with the matter, and has any other method of scale removal been attempted? The author appears to be satisfied with the governing of the output of the combined boiler and turbine being effected at the boiler. It seems to me to be essential, however, in order to overcome the storage capacity of the steam-pipe system, etc., that governing should be effected at the turbine also.

Mr. R. Dowson: On pages 165 to 167 the author justifies working with variable boiler pressure, and claims this as thermodynamically advantageous. The theoretical proof given of the feasibility of operating a boiler at variable pressure does not answer the question: Where is the advantage of operating a turbine on variable load with variable boiler pressure, over operating a turbine in a similar manner but with constant boiler pressure? The argument on page 166 about the small variation in velocity ratio of a turbine even though the load varies widely, is well known and was given by the late Sir Charles Parsons in a paper read at the World Power Conference, Berlin, in 1930. It does not, however, lend support to the use of variable boiler pressure. It merely shows that a turbine of suitable design is capable of operating over a very wide range of load without excessive loss of efficiency. It seems evident that, so far as the turbine is concerned, it does not matter whether the pressure at the inlet is varied by throttling at the governor valve or by altering the boiler pressure. Even if the Benson boiler can be operated over a wide range of pressure without loss of efficiency, the only source of gain due to a drop in boiler pressure to suit diminished load would appear to be the reduction in feed-pump power.

Mr. H. Mahon: The author asserts that Benson boilers will effect a considerable saving in cost owing to the absence of steam drums. Will this not be largely offset by the extra cost of the high-pressure steam and feed pipes, and the high-pressure turbines? I should be glad if the author could tell us something about the design of the safety-valve escape pipes. At pressures as low as 600 lb. per sq. in. the reactions due to the escaping steam are very considerable and have to be carefully considered when designing the escape pipes. This problem must be very much more acute at very high pressures, however, particularly if, in the case of a Benson boiler, the safety valve has to release steam at critical pressure to atmosphere. Could the author explain why the superheater is made a separate unit from the conversion zone? As, at critical pressure, there is no ebullition, one would imagine that it would be possible to design the superheater in the form of an extension to the conversion zone, in which case the superheat temperature could be conveniently controlled by varying the water-level and hence the superheating surface, much in the same way as the output from an electric boiler is varied by altering the level of the water in the boiler.

Mr. F. Dollin: The thermodynamic gain obtainable by raising the boiler pressure is due to the fact that, as the boiler pressure increases, the average temperature of heat input for a given final temperature is increased. For any given final temperature a practical limit to increase of boiler pressure is set by the increased amount of expansion occurring in the wet zone and the increased wetness of the steam in the last stage. The maximum economic boiler pressure is therefore dependent on the maximum permissible temperature. It would be interesting to know what limiting temperature Messrs. Siemens-Schuckert envisage in the development of the Benson boiler. A description was recently published* of a steam-car fitted with a high-pressure flash-type boiler. What is the essential difference between this type of boiler and the Benson boiler?

[The author's reply to this discussion will be found on page 179.]

NORTH-WESTERN CENTRE, AT MANCHESTER, 13TH FEBRUARY, 1934.

Mr. R. B. Potter: The paper emphasizes the modern tendency to narrow the gap between boilers and turbines, and in order to arrive at any judgment as to the commercial efficiency of such high-pressure plant as that described in the paper it is essential to consider turbines and boilers together, taking into account not only capital cost but also running charges and thermal efficiencies. Until recently I was under the impression that the *raison d'être* of the Benson boiler was the fact that it worked at the critical pressure of steam. It now appears that this is not so. Some three years ago I inspected the installation at Langerbrugge, but unfortunately the plant was not in operation at the time of my visit. I was informed that this was merely due to some minor alteration to the piping, but investigation proved that this alteration was nothing less than a complete reversal of the circulation. At that time tubular elements of spiral formation were in use, but according to the paper these have now been replaced by vertical members. I should like to know whether finality has now been reached in the design. It would be interesting to know the amount of power consumed by the auxiliaries, especially the feed pumps, expressed as a percentage of the total output of the boiler. This will no doubt be a very serious item when working at the critical pressure. As regards the scheme proposed by Messrs. Siemens-Schuckert for an installation to work with a base load of 5 000 kW but with peaks of 20 000 kW, the point that strikes me most is its complication. Two methods of firing are employed, namely pulverized fuel and stokers; I should be interested to know the reason for this. If one has gone to the trouble and expense of installing pulverized-fuel equipment for peak loads, it cannot be more efficient to employ stoker firing for base-load work. Other complications are the special feed pump which is brought into use when the pressure rises, and the special d.c. generator for providing a supply of current for the auxiliaries. Although there is no mention of it in the paper, I think that reheating will be necessary. This is certainly the case in the Langerbrugge plant, and I cannot conceive that it would be feasible to use steam at 2 000 lb. per sq. in. without reheating. I gather from the figures given for the output of the boilers that the steam consumption at maximum load is 3·6 lb. per kWh, a remarkably low value in comparison with the figure of 9 lb. per kWh which obtains in modern power stations. The capital costs given in the paper are very low, and I should like to know whether they are inclusive figures. Do they allow for a third boiler, for stand-by purposes, and do they include any provision for automatic control? The latter appears to me to be absolutely essential, but I should be interested to know how such control could be carried out. Most systems of automatic boiler control depend for their operation on the steam pressure between the boiler and the turbine, which in this case is variable. Obviously, if the load on the turbine increases, the first tendency will be to reduce the pressure until the rate of fuel feed is increased. In ordinary installations the boiler operators can watch the pressure and arrange the regulation accordingly, but when dealing with the Benson boiler they will have to be able to forecast any variations in load which may arise. It is for this reason that automatic control seems to be essential.

Mr. W. N. Y. King: The Benson boiler marks a definite and important stage in the progress of the science of steam generation; in fact quite as definite an advance as the introduction of the water-tube boiler in place of the old shell-type boilers. The particular feature in which the Benson boiler departs from the standard type of boiler in use up to the present day, is that as the water reaches the critical temperature it changes without ebullition into dry steam, and no chamber is required to separate the steam from the water. It would appear that no definite water-level is maintained, though there is a region or zone in which the process of change is going on. One of the most important factors in the working of the ordinary boiler is the necessity for maintaining the water-level constant within close limits, and it is therefore essential that provision should be made for indicating the water-level as clearly as possible at all times. I note that in the Benson boiler failures occurred due to overheating of tubes, and to remedy this the affected parts (i.e. where the water changes into steam) were removed to a region of lower temperature. I should like to ask the author how, when the boiler is working, it is visibly indicated to the operator in what part of the boiler the " change zone," if it may be so called, exists at any given moment. I take it that the position of the zone would be regulated by increasing the feed-water supply rate to raise it, and decreasing the rate to lower it. Another question that arises is, if the Benson boiler is adapted to working at below critical pressures, will there not be a definite water-level with ebullition taking place? If so, will not separate steam drums and water-level indicators be required, as in manual boilers?

Mr. V. Walker: I understand that the first Benson boilers installed at the works of Messrs. Siemens-Schuckert were regulated automatically, the pressure at the outlet of the heater tubes being maintained somewhat in excess of the critical value by means of an overflow valve, and the degree of superheat being controlled by the speed of the pulverized-fuel feeder screws. I assume that the temperature alone will now be so controlled, as the throttling of the steam between turbine and boiler has been omitted. I should like to ask the author how the steam temperature is controlled in the case of stoker-fired boilers. Are the feed pumps of the reciprocating or the centrifugal type?

Mr. C. E. H. Eckersley: Owing to the high steam pressure and temperatures obtained with the Benson boiler, the flue-gas exit temperatures from both the boiler and the economizer will be higher than obtains with the conventional water-tube boiler. On this account the preheater will naturally become essential to high thermal efficiency, and the heater efficiency will in general only be limited by the air-preheat temperature which the firing conditions permit. The fact that the series-coil boiler is considerably cheaper than other modern boilers is mainly due to the new construction, but is it not also in some measure due to the fact that the air-preheater heating surface is much cheaper than that of the boiler or economizer? The author's slides show that further saving can be effected by the adoption of the regenerative type of air-heater, owing to its extreme compactness. This can readily be seen when the Langerbrugge arrangement (Fig. 7) is examined. Although the heaters occupy negligible space, their heat recovery is probably high because the boiler is pulverized-fuel-fired. Can the author give any information regarding the temperatures obtaining in the heaters, or an indication of their efficiency?

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* *Zeitschrift des Vereines Deutscher Ingenieure*, 1934, vol. 78, p. 65.

Mr. G. A. J. Begg: I am particularly interested in the scheme proposed whereby the steam pressure of the power plant becomes a function of the load, although it is somewhat difficult to appreciate how a boiler of such small steam space as the Benson type would operate at the relatively low pressure of 500 lb. per sq. in. The curves of heat consumption of a power plant working with variable steam pressure (Figs. 15 and 16) are of particular interest, but I am rather surprised to notice the comparatively low overall thermal efficiency anticipated, in view of the rather high figures quoted for the efficiencies of the individual units. In view of the fact that the efficiency of the Rankine cycle working between the pressure limits given would be of the order of 42–43 per cent, I should have expected the overall efficiency to have been more like 26 or 27 per cent, instead of the 22 per cent corresponding to the heat consumption quoted. I presume that the difference is probably due to an allowance having been made in the heat-consumption figures for the power used by the auxiliaries.

Mr. H. Rissik: I should be interested to know to what extent, if any, the overall thermal efficiency of a high-pressure steam power plant can be improved by means of a Benson boiler steaming at constant pressure. From Fig. 16 the efficiency obtained with the Benson plant would appear to be only 20·5 per cent. Can the author give some indication as to why the Löffler boiler has not made so much headway as the Benson boiler? It has always seemed to me that the Löffler boiler is an almost ideal steam-raising unit, in that the heat from the combustion chamber is transferred directly to the steam, so that a radiant-heat type of combustion chamber completely walled by steam tubes can be employed; whilst the evaporation process takes place in a part of the water-steam circuit remote from the combustion chamber itself. Presumably the difficulties associated with this design have lain in the steam circulating-pump. In this connection I should like to know what type of feed pump is used with the Benson boiler. Is it a reciprocating pump? If so, how many stages are necessary to reach the critical pressure? Also, what percentage of theoretical kilowatts available from the steam raised in a Benson boiler is represented by the power required by the feed pumps?

Mr. B. Mitroff: I should like to know how many Benson boilers have been built, and what is the output of the largest boiler of this type in operation.

THE AUTHOR'S REPLY TO THE DISCUSSIONS AT LONDON, NEWCASTLE, AND MANCHESTER.

Mr. F. Ohlmüller (*in reply*):

LONDON.

Mr. Roles would like to hear more about the operating results of the Benson boilers which have actually been installed. I am glad to state that the two Benson boilers in the cable works of Messrs. Siemens-Schuckert at Berlin-Gartenfeld are working satisfactorily in every way. The first of these boilers was erected in 1927, the second in 1929. Both are pulverized-coal fired, the first having a maximum capacity of 25 tons per hour, and the second delivering 45 tons per hour at the peak. The boilers were operated at the critical pressure until 1932, since when they have been working at sub-critical, variable pressures, as pointed out in the paper.

Equally good results can be reported of the Benson boiler fitted to the Hamburg-American freight steamer "Uckermark," which has now been making the voyage from Germany to the Dutch East Indies for 4 years. If the Benson boiler had not proved its ability to meet the severe operating conditions involved in this service, the Hamburg-American line would probably not have hesitated to replace it by a normal-type marine boiler. For the first 2 years the Benson boiler on the "Uckermark" was also operated at the critical pressure, and the steam was throttled to the inlet pressure of the high-pressure turbine, i.e. about 1 000 lb. per sq. in. During 1932 the boiler was altered to enable it to work at sub-critical, variable pressures, so as to deliver the steam at the exact pressure at which it is wanted.

The Benson boiler at Langerbrugge has been in operation for more than 2 years, but a number of troubles had to be overcome and it was not until recently that the boiler reached the state of satisfactory normal operation. The first troubles were due to the deposition of salts. At the time the boiler was built the behaviour of the salts in the tubes (described in the paper) was not known. After the necessary re-arrangements of the tubes had been made, fresh trouble arose owing to a change in coal. The new type of fuel caused heavy slag and ash deposits at the entrance to the convection zone. For these and other reasons of design, it became necessary to substitute vertical for coiled tubes in the combustion chamber. The success of this change has been very marked, and the boiler is now operating to the full satisfaction of the customer.

Mr. Roles's remark that cross-drum marine-type boilers—such as those used at Bradford and in a number of American stations—are quite suitable for pressures up to 1 400 lb. per sq. in. is correct. This figure, however, is about the upper limit for natural-circulation boilers, whereas the Benson boiler has no pressure limit at all. The efficiency of the Benson boiler, like that of any other boiler, depends only on the amount of heating surface installed in the lower flue-gas region, which is a matter of first cost. Since, however, the Benson boiler consists only of tubes, whereas normal boilers have also heavy and expensive drums, the Benson boiler is necessarily the cheaper.

Regarding the price of 105 reichsmarks per kW mentioned in the paper, this is meant to include the entire plant with machinery and electrical equipment, transformers, and switchgear, normal foundations being provided. Pure peak-load stations could be built still more cheaply, whereas base-load stations would be more expensive.

Mr. Roles's remarks about the troubles at Bradford caused by salt deposits in the superheater are very interesting and confirm our own measurements. I am also glad to note his acknowledgment of the superiority of the Benson boiler over the normal drum-type boilers with respect to the scavenging of the tubes during operation. Our tests for locating the deposits were carried out by taking samples from various parts of the heating surface.

Mr. Roles raises the question of what should be regarded as " good " feed water. First of all, good feed water should contain no hard-scale-forming salts; this is an almost universal requirement for high-pressure boilers. For the Benson boilers of the Gartenfeld Cable Works we use condensate with make-up water from evaporators, the concentration of this make-up ranging around 20 parts per million. The water is slightly alkaline. Thus the concentration of the feed water is of the order of 2 to 5 parts per million, but there would be no harm in using feed water with a considerably higher concentration, provided the boiler was scavenged at shorter intervals. On the " Uckermark " a 16-hour test was run once in order to determine the influence of a condenser leakage; the results proved that the Benson boiler could stand without trouble a concentration gradually increasing up to approximately 800 parts per million.

In thanking Mr. Bugden and Mr. Wallis for mentioning something of the history of the Benson boiler at Rugby, I should like to express my regret that in the advance copies of the paper it was stated that several tube burn-outs occurred at Rugby, whereas, as Mr. Bugden points out, only one tube failure happened there, this being due to faulty material.

Contrary to Mr. Bugden's opinion I wish to point out that the field of application of the Benson boiler is not at all restricted to land installations, nor especially to base-load stations. The Benson boiler finds an almost wider field of application in marine plants, where the saving in weight and the quick starting are of special importance, and also in peak-load stations.

The fact that not more than eight Benson boilers (not five, as Mr. Bugden asserts) have been built so far is merely due to the general business depression. We are not disappointed about this, however, because, if a larger number of boilers had been built before the technical development had reached the present state, we should only have had more difficulties and the capital cost involved would have been much larger than it has been, whilst the value of the development would have been no greater.

Mr. Selvey mentions the problem of salts carried over from the boiler to the turbine. We have made very careful tests in this connection, but I cannot say very much about them at present, except that the various salts differ greatly in behaviour.

That the boiler and turbine are growing more and more into a machine regulated by fuel and air is pointed out by both Mr. Selvey and Mr. Bridge. This is entirely true, and I see a great improvement in that development. Although Mr. Selvey is right in stating that the tendency in power plant engineering is in the direction of avoiding heavy load fluctuations as much as possible, I still believe that there remains a wide field for the type of peak-load plant described in the paper, which is not only destined to run for the short period of the peak but has also to carry a continuous base load at high efficiency.

Mr. Burge regrets that no figures are given in the paper for the theoretical thermal gain obtainable with the Benson boiler and high-pressure turbines. I purposely omitted such figures because, since the early days of the high-pressure era, a great deal of attention has been devoted to such figures in the technical Press.

Roughly speaking, the figures presented by Mr. Burge are correct. That at Langerbrugge the theoretical gain is not fully realized is due to the fact that the high-pressure turbine was originally not intended to deliver more power than was required by the feed pump, the idea being to install at a later date, after the plant had been increased in size, a larger and highly efficient high-pressure turbine.

The feed-pump problem is no longer a problem of the Benson boiler. As long as it was believed to be necessary to generate steam at the critical pressure even when it was needed at much lower pressures, there were of course some losses. To-day, however, the feed-pump work required by the Benson boiler differs from that of normal boilers only on account of the fact that the higher velocities of water and steam make the pressure-drop in the boiler somewhat larger.

Mr. Burge raises the question whether operation at variable pressure was really believed to bring about any gain in itself or whether it was merely recommended for the sake of expediency on account of the feed-pump losses. The original idea when departing from the critical pressure was, of course, to run the Benson boiler at no higher pressure than was needed, but this would simply have led to the mode of operation employed in any other boiler, namely at constant pressure. The idea of operating the Benson boiler at variable pressure is entirely new and should rather be looked at from another angle, the main idea being that both low base loads and extremely high peaks should be carried by the same turbine with a very simple regulating mechanism and with equally good efficiencies.

Mr. Bridge's first question refers to the thermodynamic efficiency of the throttling process. As long as the critical pressure was to be maintained irrespective of the pressure in the live steam main, an overflow valve was employed between the Benson boiler proper and the superheater. Such throttling, however, never brings about a loss of total heat, but only a drop in temperature due to the well-known Joule–Thomson effect. In the Mollier chart the throttling process is shown by a line of constant total heat from left to right, i.e. towards greater entropy. The throttling valve has now been entirely dispensed with, as mentioned in the paper.

The moisture in the last stages of the turbine increases as the live steam pressure is raised with increasing load. From Fig. 13 it will be seen that at the lowest pressure the moisture content is about 8 per cent, whereas at the highest pressure it reaches 15 per cent. In the example shown in Fig. 13, however, the highest pressure will be maintained only for the very short period of the peak load, so that the 15 per cent moisture will do no harm. If, however, the load diagram of a plant is so shaped that the maximum load is to be carried for longer periods, then it will be necessary to provide reheating, which, moreover, increases the cycle efficiency.

Mr. Bridge doubts the feasibility of the operation of auxiliaries from a supply of variable frequency, as outlined in the paper, and mentions the great efforts now being undertaken in Great Britain to standardize frequency at 50 cycles per sec. In reply I would point out that the variable-frequency auxiliary set merely serves those auxiliaries within the power plant that have to work at widely varying speeds, and will have no bearing whatsoever on the frequency of the system.

Mr. Wallis refers to the tube arrangement in the combustion chambers of the Benson boilers at the Gartenfeld Cable Works and at Langerbrugge. In the former boiler the originally straight vertical tubes were later replaced by helically wound coils, because we wanted to avoid the loops at the bottom and the downward flow in a relatively large number of parallel tubes. We also wanted to be free from possible irregularities of the burners, as Mr. Wallis pointed out. Whereas at the cable works the design of the helically wound coils proved to be very successful, we had troubles with the same design at Langerbrugge owing to the larger size of the boiler. In the meantime another type of tube arrangement had been developed and successfully tried out on the steamer "Uckermark." This consisted again of straight vertical tubes, but there was always one bundle of parallel tubes connected to one downcoming tube leading to the next bundle, as shown in Fig. 3. Radiant heating elements of this type were recently installed at Langerbrugge, to replace the original helical coils, and have given good results there.

Mr. Wallis further asks whether gilled tubes have ever been tried in Benson boilers. We have not used them so far, and I doubt whether they will be used in the future, because we prefer tube coils of rather small diameter and very closely wound.

In answering Mr. Wallis's question about the policy with regard to the manufacture and sale of Benson boilers, I can state that the American licenses for land and marine boilers have been acquired by the Westinghouse Electric and Manufacturing Co., of South Philadelphia, that the marine-boiler license for Germany is in the hands of Messrs. Blohm and Voss, of Hamburg, and that Messrs. Siemens-Schuckert have the manufacturing rights for land boilers in Germany and a large number of other countries. The manufacturing rights in countries for which licenses have not yet been granted (e.g. Great Britain) rest with the Internationale Benson-Patentverwertungs Co., a holding company, of Zurich, Switzerland.

Mr. Pratt's question refers to those many cases where a new prime mover has to carry only a small fraction of its rated load during the first years after its installation. If (as is usual in such cases) the steam is generated at the constant pressure at which the plant will work later when fully loaded, and for which it is thus laid out, then the turbine will work most of the time with the very bad efficiencies associated with light loads. Here is the field of the variable-pressure Benson boiler, the expression "variable pressure" meaning not, or at least not only, the variation of pressure with the load fluctuations during a day, but rather the gradual adaptation of the steam pressure to the load of the turbine as it is changed within a period of years. While the load is still low the pressure will be kept down, and as the load becomes greater on account of an increase in the number of power consumers on the system the pressure will be raised to such values as will always give the maximum turbine efficiency. When steam is used at higher pressure and the vacuum may not be lowered, it will be feasible to build a few more stages of expansion in the turbine at the low-pressure end. It is easy to allow spare space for this at the outset, and the stages can be provided very quickly and at low cost. Except for this addition nothing need be changed at the turbine. The generator must, of course, be large enough from the beginning to carry the entire load. The condensing plant may be either laid out for the full output from the beginning or built in the first place for the preliminary partial load and later enlarged by the installation of a second condenser. The chief advantage of such a gradual enlargement is that the cost of the initial installation is kept low and the power plant remains always flexible as to possible future developments.

Answering Mr. Martin, a detailed project has been worked out for a locomotive equipped with a Benson boiler for the German State Railways. The steam temperature of 450° C. given in the paper was merely meant to be a safe value. We would not hesitate to use temperatures of 500° C. and more.

The flue-gas velocities in the Benson boiler are as a rule the same as those in any normal-type boiler, but we have also worked out some projects with considerably higher flue-gas velocities, the combustion occurring under pressure. Speeds of the order of from 6 000 to 10 000 ft. per min. were found to be the most economical values. The Benson boiler on the "Uckermark" has not been altered as to the flow of the flue gases since the vessel went up the Thames. The efficiency of 91·5 per cent referred to by Mr. Martin was obtained on a test run of the ship on one of her regular voyages.

NEWCASTLE.

Mr. Gibb doubts the feasibility of variable-pressure operation. With respect to the charts given in Fig. 11, there may occur, of course, still larger fluctuations, e.g. a drop from full load to 10 per cent load. The manœuvring of the "Uckermark" proves, however, that the

Benson boiler follows these fluctuations very easily. This, indeed, is an oil-fired boiler, but even stokers, both under-feed and chain-grate, have been developed to such a degree of flexibility as to meet all operating conditions. The answer to Mr. Gibb's inquiry as to the price of the power plant described in the paper is given in my reply to the remarks of Mr. Roles.

The turbine efficiencies can be increased, provided that higher values are needed. In the present case, however, it was not intended to build a turbine with the highest possible efficiency, but rather to build a machine so fitted in the general lay-out of the plant that the total costs became a minimum. The steam-consumption curves given in Fig. 16 are by no means wrong. The difference between the curves *b* (constant pressure) and *c* (variable pressure) is not so much due to the higher pressure at *c*, but rather to the fact that in the case of *b* the full efficiency is only reached during the short peaks, whereas during the rest of the time the turbine has to work with the poor efficiencies of partial loads. In the case of curve *c*, however, when the pressure is allowed to vary, the efficiency is equally good at nearly all loads.

Mr. Gibb can see no fundamental reason why the Benson boiler should be more suitable for variable-pressure operation than any drum-type boiler, except for its ability to respond quickly to steam-demand variations. This is an error, because for high-pressure operation the drums must have and can have relatively small diameters, whereas at low pressures much larger drums are required to ensure sufficiently large surfaces of evaporation, if priming and foaming are to be avoided. Furthermore, the ratio of the total sensible heat of the water to the latent heat, and to the superheat, varies so greatly within the pressure limits under consideration that a drum boiler with its fixed heating surfaces of economizer, boiler proper, and superheater, will never be able to deliver steam of constant temperature. In a Benson boiler, however, although the heating surface is subdivided into a number of separate bundles, there exist no boundaries between boiler proper and the superheater; but the point of dry saturated steam is allowed to move back and forth so as always to ensure a constant temperature at the superheater outlet.

Mr. Bottomley's first question refers to the cost of power plants. A highly efficient 600 lb. per sq. in. base-load station of the ordinary type would cost about 180 reichsmarks per kW, whereas a mere peak-load station working at constant pressure could be built for approximately the same price as is given in the paper for the plant operating at variable pressure, namely 105 reichsmarks per kW. Such a normal peak-load station has a poor thermal efficiency, however, and therefore ought to be operated only for the short hours of the peak, whereas the advantage of the variable-pressure plant is that it combines the low cost of a peak-load station with an efficiency nearly as good as that of a base-load station, so that it can carry both the base load and the peaks. Regarding spare capacity, I do not believe that it would be practical to install so many small units, which are necessarily more expensive than larger machines.

Mr. Bottomley also touches on the very interesting problem of the regulation of turbines working at variable pressure, which still needs some explanation. On page 165 it is stated that the throttling of the steam between the boiler and the turbine has been abandoned. Instead, the governor of the turbine acts directly on the automatic boiler control in such a way that, when the load on the generator is increased and the speed of the turbine tends to drop, the boiler receives more feed water, more coal, and more air for combustion, which results momentarily in a greater steam output of higher pressure but constant temperature. The impulse for the boiler control can also be taken directly from the wattmeter of the generator instead of from the turbine governor.

If the turbine works in parallel with other machines and is loaded according to a load schedule, the frequency of the system being maintained by another machine, the governor can be dispensed with. In actual practice, however, a governor is provided, since those turbines that are normally operated in parallel with others must also be able to run alone, at least when they are connected to the line. After such a machine has been synchronized and connected in parallel, one can disconnect the governor from the inlet valve and adjust the load to be carried by the turbine by means of the automatic boiler control; or, better, one can set the governor so that it acts to close the throttle valve at a given overspeed, which must be somewhat below the speed at which the emergency stop-valve would close, so that the latter does not trip.

When the turbine is working alone and has to maintain frequency, the governor is always in operation, but it acts on the automatic boiler-control mechanism and not on the throttle valve before the turbine. If the boiler could follow these impulses quickly enough, the operation of the turbine would be satisfactory. As there is a time-lag, however, it is well to keep the throttle valve at the turbine inlet partially closed. Consequently, when in the event of a quick increase of demand the valve is suddenly opened wide, there follows immediately an increased steam flow to carry the first peak, until the boiler regulation has brought the boiler to higher output. In cases of very quick and heavy load increases, we close from the governor the bleeder connections to the feed-water heaters, thus using the full adiabatic drop in the turbine. This gives a considerable momentary increase of the output, and in the meantime the boiler can follow the load demand. The temporary variation of the feed-water temperature can be compensated by the installation of a small open heater.

When the load drops suddenly, the turbine works like one with normal throttling regulation. Should the pressure in the live steam main rise too high, part of the steam is bypassed through a relief valve directly to the condenser, as is done during quick manœuvring on the "Uckermark."

Mr. Bottomley further asks how the regulation of a plurality of Benson boilers is manipulated, when the feed pumps discharge into a common feed range and the steam from the boilers is fed into a common steam range. In such an installation we give every boiler a regulator of its own and let the pump be controlled from differential pressure impulses.

Mr. Waring raises the question whether it would be advisable to use Benson boilers in an industrial plant that has to use chemically treated make-up water to the extent of, say, 30 per cent. The Benson boiler, when correctly scavenged, can be safely operated with chemically treated feed water. With respect to the carry-over of salts to the turbine, however, a problem which also affects every normal-type boiler unless special precautions are applied to secure absolutely dry steam, we let that part of the steam which would have to be replaced by make-up water, exhaust into a closed heater or steam transformer, maintaining a closed circuit in the high-pressure system.

Mr. Waring's second question, regarding the alkalinity of the feed water, has been answered already in my reply to Mr. Roles. Of course, the alkalinity is much smaller than that of the boiler water in normal drum boilers.

Mr. Hayward's remarks about the shutting-down of the Benson boiler at Langerbrugge refer to an accident that happened in the early days of its operation, when one of the attendants, who was not yet familiar with the boiler, shut off the feed pump without taking out the pulverized-coal burners at the same time. On a subsequent occasion the voltage failed throughout the entire plant, and consequently the auxiliaries too. The operator of the Benson boiler immediately shut off the burners, and no damage was done to the tubes. The output of the high-pressure turbine at Langerbrugge is approximately 4 000 kW. The feed pump requires 1 700 kW at the critical pressure, and correspondingly less at lower pressures, the balance being available as electrical output.

Mr. Jackson wonders how the scavenging of a Benson boiler is carried out. Imagine a drain valve in each bundle of tubes at the end of the conversion zone. Normally all these valves are closed. When a tube bundle is to be scavenged the valve is opened and at the same time the output of the feed pump is increased by the amount that is blown down through that valve. Thus one bundle is blown down after the other. If desired, the sensible heat of the water blown down can be recovered in a closed heater, or the water can be evaporated.

Mr. Jackson also refers to the question of regulation, thereby pointing out the effect of the steam stored between the valve and the steam chest of the turbine. My reply to Mr. Bottomley's question having made clear that it is not intended to dispense with the throttle valve at the turbine inlet, it will be readily understood that in case of emergency the steam can be shut off very quickly.

I should like to thank Mr. Dowson for his reference to the paper contributed by the late Sir Charles Parsons to the World Power Conference, Berlin, in 1930. I feel, however, that the ideas which this expresses are appreciably different from those given in the present paper. The main object of Sir Charles Parsons was to prove that the steam turbine is essentially fit for overloading and that its efficiency remains substantially constant over a very large range of load. He had in mind, however, that the pressure in the steam main should be held constant; so that at low loads the steam would have to be throttled, and at overloads additional live steam would have to be let into intermediate stages of the turbine. When the variable-pressure method is employed, however, there is always the full amount of steam and at the pressure at which it is generated, flowing to the first stage of the turbine.

In plants operating at constant pressure the steam temperatures at the various stages of the turbine differ widely with varying load, firstly because of the characteristics of the superheater (which usually delivers much cooler steam at low loads than at high loads) and secondly because of the throttling at low loads, which also results in a drop of temperature. On the other hand, at overloads the steam temperatures rise, owing to the addition of live steam into intermediate stages. When a plant is operating at variable pressure, however, the temperature of the steam at each individual stage is constant irrespective of the load, so that load fluctuations can be followed much more quickly and safely.

To sum up the main advantages of the variable-pressure method of operation, I name the following: (1) Simple and cheap turbine design. (2) High and constant thermal efficiency, irrespective of load. (3) Constant temperature throughout the turbine, irrespective of load.

Mr. Mahon seems to believe that high-pressure plants are considerably more expensive than low- and medium-pressure plants, and that the gain due to thermal savings is therefore offset by higher capital cost. This is not true. Now that the commercial stage of the development has been reached, the costs of a high-pressure plant are by no means higher than those of a normal 500 lb. per sq. in. plant.

The safety valves for critical-pressure operation were newly designed when the first Benson boilers were erected. They are built both spring-loaded and with counterweight. The closing is effected by a ball made of a very hard alloy steel. The superheater is usually made as a separate bundle of tubes and not in one unit with the conversion zone, because it has to be exposed to higher flue-gas temperatures and therefore has to be placed nearer to the combustion chamber than the tubes of the conversion zone.

Mr. Dollin's question regarding reheating has been dealt with already in my reply to Mr. Bridge.

MANCHESTER.

Mr. Potter's first question relating to the design of the Benson boiler at Langerbrugge has been answered already in my reply to Mr. Wallis. The power required by the feed pump at critical pressure ranges between 3 and 4 per cent of the turbine output. At lower pressures the power required is correspondingly less and essentially the same as that of other types of boilers. The combined use of a stoker for base load and of pulverized-coal burners for the peak is by no means a complication, but was purposely chosen as the most economical way of firing for that type of plant. Nor can I see any complication in the use of two feed pumps, one of which is to carry the normal base load, and the other operating at variable pressure, is to be put in the line only when the peak comes on. The question of reheating has been dealt with already in my reply to Mr. Bridge.

Mr. Potter criticizes the figure of 3·6 lb. per kWh obtained by calculation from the steam output of the boilers as given on page 167. In his calculations, however, he has been misled by the fact that the figure of 36 000 lb. per hour mentioned in the paper does not represent the full maximum steaming capacity of a boiler, but merely the maximum to be obtained with the stoker. Beyond this output the pulverized-coal burners are put in, and with them a total of 100 000 lb. per hour per boiler can be reached. This gives 200 000 lb. per hour for the two boilers together, corresponding to a value of 10 lb. per kWh, whereas at normal load (5 000 kW) the figure is 9 lb. per kWh, which is in good accord with what Mr. Potter expected. The questions of costs and of the regulation have been dealt with in my replies to Mr. Roles and Mr. Bottomley respectively.

Mr. King raises the question how, when the boiler is working, it is visibly indicated to the operator in what part of the boiler the conversion zone exists at any given moment. As a matter of fact this zone need not be visible at all; the operator has merely to maintain a constant temperature at the superheater outlet. It is the task of the designer to place the conversion zone in such a part of the flues and to dimension the various parts of the heating surface in such a way that the conversion takes place at the desired spot.

In reply to Mr. Walker, the temperature control is in all cases effected by changing the rate at which the fuel is supplied. In oil-fired boilers the pressure of the oil is varied, or additional burners are put into service; in the case of pulverized-fuel-fired boilers the speed of the feeder screws is varied; with stoker-fired boilers the speed of the stoker and the air supply for combustion are varied.

Both reciprocating and centrifugal pumps are used in connection with Benson boilers. Reciprocating pumps are preferred for small outputs up to, say, 50 to 70 tons per hour, whereas for higher outputs these pumps become too large and therefore centrifugal pumps should be used.

Mr. Eckersley's remark that the high steam pressure and temperatures obtained with the Benson boiler prevent low flue-gas exit temperatures, does not hold good, since all Benson boilers have economizers and the feed-water temperature need not necessarily be higher than that prevailing with normal boilers. Notwithstanding this, all Benson boilers have been equipped with air preheaters. The compactness of the Ljungström-type air preheater, as shown in the illustration of the Langerbrugge boiler (Fig. 7), is certainly an advantage. Answering Mr. Eckersley's last question, I can give the following data taken from the acceptance tests of the Langerbrugge boiler carried out by Prof. Josse, of Berlin-Charlottenburg. The figures refer to normal load.

	Air-heater inlet	Air-heater outlet
Air temperature, °C. ..	49	353
Flue-gas temperature, °C.	467	236
CO_2 content, per cent ..	16·0	13·8

Mr. Begg refers to the overall thermal efficiency as calculated from the Rankine-cycle efficiency, the boiler, turbine and generator efficiencies, and the power consumption of the auxiliaries. First of all one must bear in mind that the plant described in the paper employs a high pressure not in order to secure the utmost thermal efficiency but with a view to making a cheap peak-load machine possible. Therefore, the Rankine-cycle efficiency at the peak load is not of the order of 42 to 43 per cent, as Mr. Begg assumes for his calculations, but is restricted to about 40 per cent. The product of boiler efficiency, turbine efficiency, and generator efficiency, is, roughly speaking, 60 per cent, so that a gross overall efficiency of the order of 24 per cent results, leaving 2 per cent for the drive of the auxiliaries. For normal load the cycle efficiency is some 2 per cent higher, owing to the better vacuum combined with regenerative feed-heating. The overall thermal efficiency at normal load (5 000 kW) is 23·8 per cent, including the power consumption of the auxiliaries. Other figures for the possible maximum efficiency are given below.

Mr. Rissik refers to the comparison made in Fig. 16 between the Benson boiler operating at variable pressure and a plant operating at constant pressure, the pressure being lower and the superheat less. The average overall thermal efficiency calculated for that type of plant is 20·5 per cent, as Mr. Rissik correctly quotes, but this figure should not be taken as the value for a Benson plant. The maximum thermal efficiency obtainable with the Benson boiler working at critical pressure, with multi-stage heating and reheating, reaches that of the Diesel engine (about 32 per cent). This corresponds to a theoretical cycle efficiency of over 50 per cent, which is very close to the Carnot efficiency. In practical cases the costs for the multiple-stage heaters and reheaters are too high to warrant such an installation, the economic optimum lying at values of the order of 27 to 28 per cent.

Mr. Rissik's question relating to the feed pumps for the Benson boiler has been answered in my reply to Mr. Walker. The reciprocating feed pumps installed at the Gartenfeld Cable Works and on the "Uckermark" are used to compress the water in one stage directly up to critical pressure, all cylinders working in parallel. The question of the power consumption of the feed pump has already been answered.

Mr. Mitroff's question leads me back to the beginning of my reply, where I enumerated all the Benson boilers now in operation. The largest is that at Langerbrugge, which has a capacity of 135 tons per hour.

GRID METERING.

By J. HENDERSON, M.C., B.Sc., Associate Member.

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SUMMARY.

The paper discusses the problems of summation metering arising from the requirements of the 1926 Act, and it indicates the reasons which led to the choice of impulse instead of electrical summation on the larger equipments. For duplicate circuits the latter has been adopted as being simpler and less expensive. The types of meters installed were specially designed for grid metering purposes, and the accuracy obtained is an advance on previous requirements.

The methods of impulse transmission and reception are described and compared, and it is shown that for uniform accuracy and performance "graded" impulsing is essential. The rate of impulsing has a decided effect on the life of the equipment and also on its accuracy. Considerable experience has already been gained in several of the grid districts, and the modifications which have been made to weak designs have resulted in consistent and accurate records.

The large financial transactions dependent on the metering records make exacting demands on the equipments, and the number of operations performed annually necessitates constant and regular maintenance, for which a suitable programme is suggested.

The number of faults to be expected on a satisfactory equipment is indicated, and it is shown that, although the majority of these are of a minor nature, delay in drawing up fault reports may result in the records being lost at a critical period.

INTRODUCTION.

In the consideration of grid metering, its operation and maintenance, reference must be made to the Electricity (Supply) Act of 1926, which specifies the quantities to be measured at each grid connecting-point. The ground has already been partly covered by C. W. Marshall,* but as this paper was written during the early stages of development its scope is limited to a general outline of the proposals, with descriptions of one or two details of particular interest at that time.

In May, 1931, a comprehensive memorandum dealing with grid metering and the methods of complying with the requirements of the 1926 Act was issued to all authorized undertakers. In this memorandum specific information is given as to the methods of obtaining records on which accounts may be based, and all grid points are classified under four main types: A. Selected generating stations. B. Grid supply points without generation. G. Group selected stations. J. Non-selected generating stations operating under the control of the Board. As the memorandum has been in the hands of those interested for some considerable time, it is not proposed to discuss it further in this paper.

The following records are required during each monthly accounting period: (*a*) Kilowatt-hours. (*b*) Kilowatts of maximum demand during any consecutive 30 minutes. (*c*) Power factor at the time of maximum kW demand. The demand period of "any consecutive 30 minutes" is defined as follows in Order No. 1015 issued by the Electricity Commissioners in 1929. "The expression 'any consecutive 30 minutes' shall mean either 30 minutes from the commencement or 30 minutes from the middle of any hour of the 24 hours of any day."

At the time of the 1926 Act the kWh readings could have been obtained on the most complicated of multiple circuits by simple addition or subtraction. The measurement of the simultaneous demand on a number of circuits is a more difficult problem, however, and although there are only two general methods by means of which this can be done, each method is subject to considerable variation in detail. It is the object of this paper to discuss the methods adopted and to describe designs by which the problem has been solved.

TABLE 1.

District	Number of meters	Number of summators	Number of impulse units
Central Scotland ..	303	67	282
S.E. and E. England ..	1 247	199	1 152
S.W. England	338	72	284
Mid-East England ..	530	110	436
Central England ..	440	114	398
N.W. England ..	827	184	968
N.E. England	233	44	186
Totals	3 918	790	3 706

The determination of power factor at the time of maximum kW demand by means of reactive-kVAh meters involved practically a duplication of the kW demand apparatus, and this has been done in all cases where power factor is involved in the Board's agreements or tariffs.

The extent of the grid metering contracts will be seen by reference to Table 1, where the details of the metering equipments are summarized. The figures given are approximate only, and cannot be regarded as a permanent record of the grid equipment, in view of the extensions which are continually being made.

In view of the very large transfers of energy which are the subject of the financial agreements between the Board and the various authorized undertakers, it was essential that the most accurate metering equipment obtainable should be installed. The standards of accuracy previously adopted were those specified in B.S.S. No. 37—1919 for electricity meters. Including the current- and potential-transformer errors, the specified grid accuracy requirements which were agreed upon after consultation with the responsible meter designers are summarized in Table 2, which also gives for comparison the relative figures from the British Standard Specification. The meters are in all cases required to start at a load not exceeding 0·5 per cent of the full rated load.

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* *Journal I.E.E.*, 1930, vol. 68, p. 1497.

A higher standard of accuracy is required for the Board's circuits than that specified for generator circuits, owing to the fact that precision current transformers have been installed on the Board's circuits, as compared with Grade A for other circuits. If consideration is given to the running conditions in each case, the reason for the difference will be apparent. Generators seldom operate for any considerable time at less than half load, while in the case of the grid circuits floating-conditions often obtain for long periods and the import or export is a relatively small fraction of the total capacity, which may have been chosen to meet future requirements or for emergency purposes.

TABLE 2.

Range of load	B.S.S. No. 37—1919	Limits of error at unity power factor		Limits of error at zero power factor	
		kWh meters		Reactive-kVAh meters	
		Board's circuits	Generator circuits	Board's circuits	Generator circuits
per cent		per cent	per cent	per cent	per cent
125—100	—	0·5	1·0	2·5	2·5
100—20	2·5	0·5	1·0	2·5	2·5
20—10	2·5	0·5	1·0	2·5	2·5
5	5·0	2·0	2·0	2·5	3·0

KILOWATT-HOUR METERS.

To meet the requirements of the grid specifications the British manufacturers put forward specially-designed meters, and four of these designs have been installed on the grid. These types have been designated A, B, C, and D; they are compared in detail in Table 3.

The specifications required that in the event of a reversal of phase rotation on the kWh meters the accuracy should still be within the limits prescribed for correct phase-rotation. Interaction between elements must therefore be very small, and two of the manufacturers have adopted the closed-circuit electromagnet to reduce this to a minimum.

A notable feature of the Type B meter is the introduction of double driving elements and a duplicate braking system on each disc, in order to obtain balanced torque on the meter spindle.

Diamond jewels were specified for all meters and have been supplied in Types B and C. Synthetic sapphires have been accepted on the other types, and a special oil is used for lubrication. Experience is not yet sufficient to enable a conclusive comparison between the two types to be made.

The maximum specified temperature-coefficient on the grid meters is 0·1 per cent per deg. C. variation in air temperature, and this requirement has been met by all manufacturers. While the range of temperature may exceed 25 deg. C. in special cases, artificial regulation would be resorted to in such circumstances in order to maintain the meters and instruments in good condition, so that it is unlikely that a temperature range exceeding 15 deg. C. would be met with in practice. This would result in a maximum temperature error of ± 0·75 per cent. The error in an a.c. meter at full load and unity power factor is positive with increase in temperature, owing to weakening of the brake-magnet flux. At

TABLE 3.

Type of meter	A	B	C	D
Full-load torque, g.cm	6·8	20	8 (1), 14 (2)	20–25
Speed of rotor, r.p.m.	40	27·7	24	16–24
Weight of rotor, g	25	81·5	51	66
No. of brake magnets	4	8	4	4
Type of suspension	Spring	Magnetic	Spring	Spring
Type of jewel	Synthetic sapphire	Diamond	Diamond	Synthetic sapphire
Magnetic circuit	2 closed circuits	4 single circuits	2 closed circuits	2 separate shunt and series circuits
Potential compensation of reactive-kVA meters	Internal shunt resistance	External quadrature transformer	Internal shunt resistance, parallel resistance to series coil	External, phase-to-neutral voltage
Type of impulsing contacts . .	Commutator	Cam	Gravity	Cam
Temperature coefficient, per cent per deg. C.	Less than 0·1	Less than 0·1	0·09 reactive kVAh 0·04 kWh	Less than 0·1
Volt-amperes (series)	2 × 1	2 × 1	2 × 0·4	2 × 1
Volt-amperes (shunt)	2 × 10	2 × 5·8	2 × 1·2 2 × 7	2 × 17

power factors below unity a negative error appears as a result of change in quadrature compensation. The net effect of increase in temperature, therefore, is a variation in the error between a positive and negative maximum. As the majority of meters are required to run at power-factor values between unity and 0·5 lagging, a much smaller error than that indicated above may be expected. Curves showing the effect of temperature on one of the Type A kWh meters are reproduced in Fig. 1.

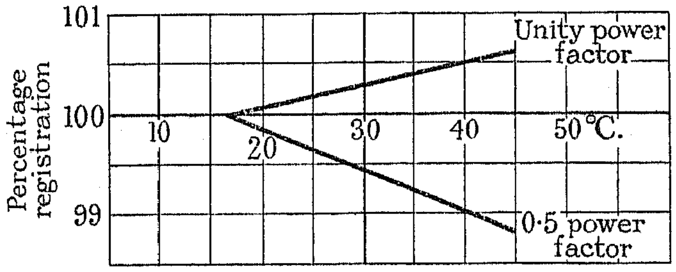


FIG. 1.

REACTIVE-KVAH METERS.

Assuming balanced conditions, the kWh meters register the value of the expression

$$EI \cos(\phi + 30°) + EI \cos(\phi - 30°)$$

and under similar conditions the registration on the reactive-kVAh meters is proportional to

$$EI \sin(\phi + 30°) + EI \sin(\phi - 30°)$$

To give this registration a reactive-kVAh meter must have the potential circuits so arranged that the voltage fluxes have the same relation vectorially to the currents as the voltage vectors have in the kWh meters. Each type of grid meter has a different method of potential compensation for this purpose, and a comparison of these is of interest.

If the necessary accuracy can be obtained it is an advantage to have the potential compensation so arranged internally that the terminal connections are uniform on both kWh and reactive-kVAh meters, as this gives correct registration on reversed phase rotation. Alternatively, the kWh and reactive-kVAh meters may conveniently be made interchangeable, if suitable external compensation is provided.

Table 4 gives a summarized comparison of the grid reactive-kVAh meters, showing the method of compensation adopted and the effect of reversed phase-rotation.

In Type B, the reactive-kVAh meter is identical with the kWh meter, and a quadrature transformer is employed to obtain the correct potentials on the meter. In the Type D meter, phase-to-neutral potentials are used, and the meter is therefore slightly different from the corresponding kWh meter. In both types, reversal of phase rotation gives incorrect registration, which is a decided disadvantage. In Type C, standard kWh-meter connections are employed with internal compensation, and on reversal of phase rotation the meter will still give the correct registration. The vector diagram showing the current and voltage relations in this case is given in Fig. 2.

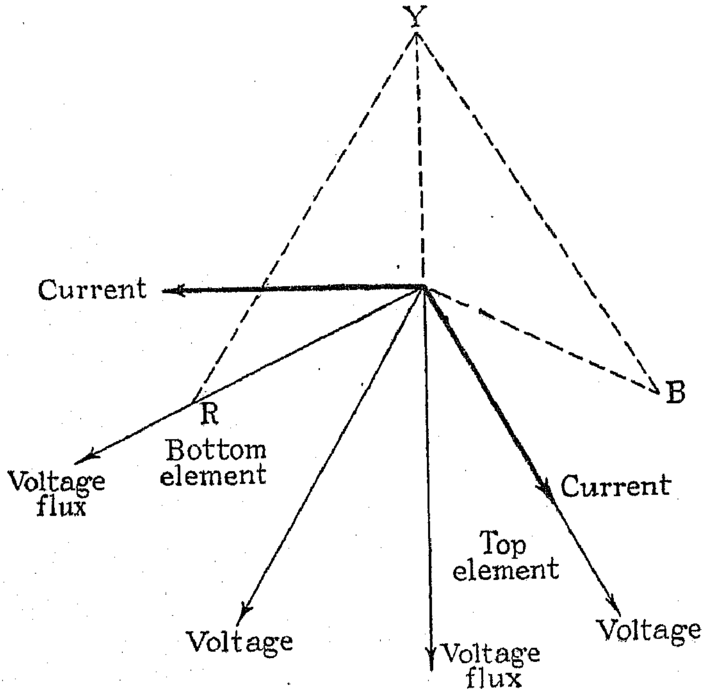


FIG. 2.

Resistance is inserted in parallel with the series coils and in series with the shunt coils to bring the vectors into correct phase relationship.

TABLE 4.

Type	A	B	C	D
Potential compensation ..	Internal	External	Internal	External
Method of compensation ..	Resistance in series with shunt coils	Auto-transformer	Resistance in series with shunt coils, resistance in parallel with series coils	Phase-neutral potentials
Comparison of connections with kWh meter	Different potentials	Different potentials derived from auto-transformer	Standard	Phase-neutral potentials
Comparison of meter with kWh meter	Resistance in series with shunt coils	Standard	Resistance incorporated in meter	Different potential coils
Effect of reversed phase-rotation	Wrong registration	Wrong registration	Correct registration	Wrong registration

WORKS TESTS ON METERS.

The grid metering specifications called for works tests on all meters, in some cases associated with their respective current transformers and making allowance for potential-transformer errors. In other cases, tests of the meters only were called for, making allowance for the errors of both current and potential transformers. Opinions differ as to which method of testing is preferable, and it is not always possible to bring current transformers and meters together before installation, especially if the time available is short. Provided the transformers are tested satisfactorily, there seems no reason why the inherent errors cannot be allowed for in calibrating the meters. In any case it would be both expensive and inconvenient to recalibrate the meters in conjunction with the current transformers, if this were found necessary at a later date. For this reason separate test certificates for the meters and transformers are essential.

CURRENT AND POTENTIAL TRANSFORMERS.

For the Board's circuits, current transformers having precision accuracy were specified; Table 5 gives the requirements. The output specified for the current transformers for the Board's circuits in Central Scotland and N.W. England was 40 VA. In other districts the figure of 15 VA was specified.

TABLE 5.

Load	Ratio variation	Phase-angle variation
per cent	per cent	minutes
125—10	± 0·30	12½
125—5	± 0·75	20
	Absolute ratio error	Absolute phase-angle error
	per cent	minutes
125—5	± 1·0	30

The potential transformers were required to comply with B.S.S. No. 81 with Grade B accuracy.

AUXILIARY CIRCUITS.

In many cases the auxiliary circuits in generating stations are both numerous and complicated, but extreme accuracy of metering is not essential. To meter the auxiliaries and make arrangements for the automatic subtraction of these readings from the readings of the generator meters would have been both expensive and unnecessary. Where the circuits are simple, auxiliary meters are installed and connected up to the generator summators for automatic subtraction. In the majority of cases, however, the existing meters are used, and the kWh delivered are obtained arithmetically. The auxiliary kW and reactive-kVA demands are agreed between the authorized undertakers and the Board as a result of tests carried out at various loads.

SUMMATION METERING.

Summation metering may be conveniently classified under the two main heads of (*a*) electrical summation, and (*b*) mechanical summation. Electrical summation is simpler and less expensive than mechanical, but the sphere of application is strictly limited. There are four practicable methods, but only two of these can be conveniently adopted for use with more than two circuits. The four methods are: (1) Four-element meters. (2) Parallel current-transformers at the meter terminals. (3) Double-wound series-coil meters. (4) Summation current-transformers.

Although with a 4-element meter it is possible to summate two parallel circuits accurately, most meter engineers do not regard this type of meter with favour. The weight of the rotor, with the consequent rapid jewel wear, is the main drawback, and it is probable that for duplicate circuits the 4-element meter will be entirely superseded in future by the simple method of paralleling the two sets of current transformers at the meter terminals or by the use of standard meters with double-wound series coils. Both of these methods are slightly less accurate than a properly designed 4-element meter, but, as the main object of summation metering is to measure maximum demand, the accuracy obtainable is usually good owing to high meter-loading.

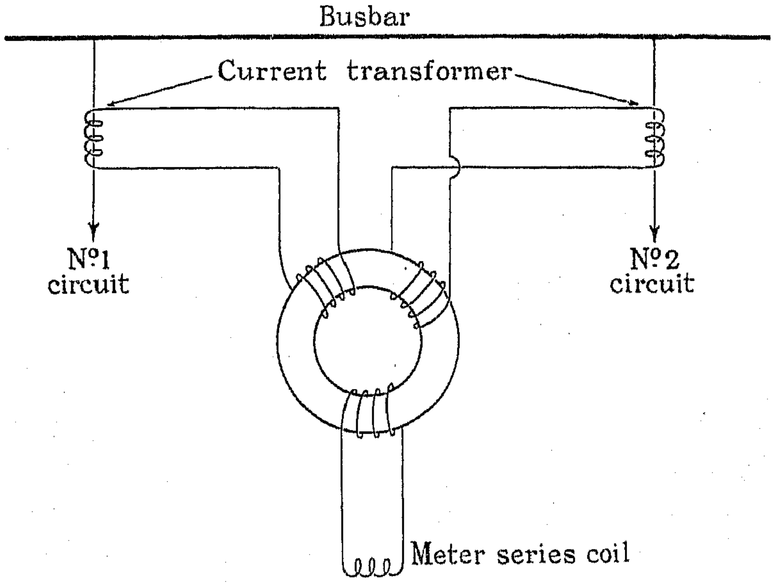


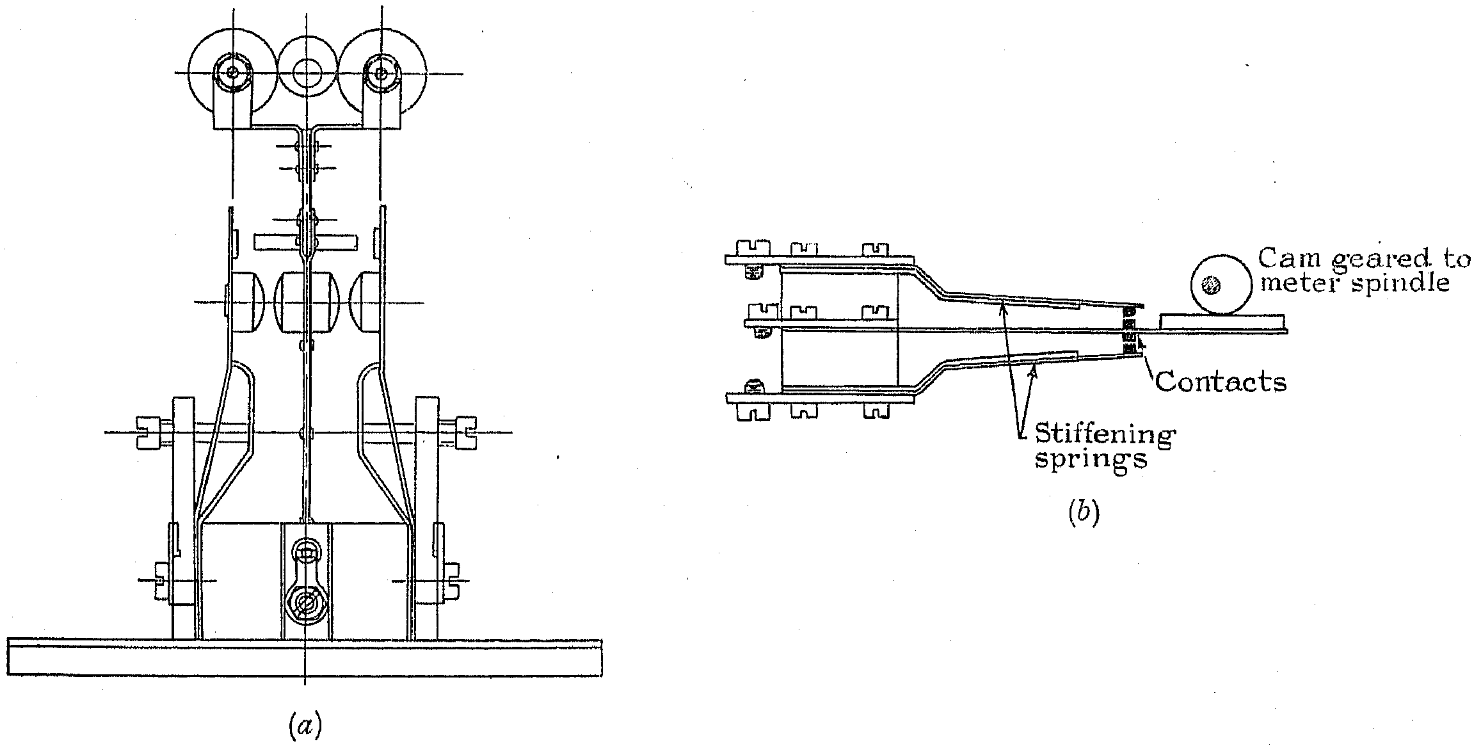
FIG. 3

For duplicate circuits importing from the grid, double-wound series-coil meters have been adopted in many cases for summating the maximum demands. In such cases the kWh are obtained by addition from two separate meters, while the maximum demand is obtained from a demand indicator on the summator meter. This meter also acts as a check on the kWh as read from the two main meters. The accuracy specified by the Board for a double-wound series-coil meter is 0·5 per cent below that for individual kWh meters. There are also many instances where current transformers have been connected in parallel at the meter terminals. This method has much to commend it as regards both simplicity and comparative accuracy. Practical considerations limit its application to three or four parallel circuits, but the inaccuracy increases with the number of circuits.

By the introduction of a summation current-transformer, the primary windings of which are in series with the kWh meters, it is possible to extend electrical summation to a still larger number of parallel circuits. The method is shown diagrammatically in Fig. 3. It is unfortunately the case that, as the number of circuits increases, the accuracy of the combined equipment decreases, and where the current-transformer ratios on the multiple circuits vary within wide limits it is not always possible to forecast what the limits of accuracy will be under all conditions.

Recognizing the limitations of electrical summation methods, the Central Electricity Board indicated a preference for mechanical summation in the metering specifications. It has been explained that, as the power in multiple circuits cannot be satisfactorily summated in the kWh meters, it becomes necessary to transmit the meter index readings to some convenient point where they can be added mechanically. This is carried out by transmitting impulses from the meters to the summators, each impulse representing a definite number of units. To transmit impulses from a meter it is necessary to have a contactor geared to the meter spindle, and the design and type of the contactor employed are most important. The ideal method is one which under all conditions of operation will impose no load on the meter itself. Such a method, however, has not yet been developed, and each contactor device imposes some slight load on the meter to which it is fitted. The following characteristics are very desirable, and in some cases necessary, in an impulse summation meter contactor. (1) The load imposed on the meter should be as small as possible, and the removal of the contactor device should not affect the meter accuracy at 5 per cent load by more than 0·5 per cent. (2) It should be possible to predetermine this load and adjust the contact mechanism to the predetermined load. (3) The load imposed on the meter should be invariable over long periods of time. (4) The contacts should be amply proportioned, both for wear and for heating. (5) The mechanism should not be affected by vibration. (6) The contact should be definite, and small reversals of the meter should not remake contact after it has actually been broken.

In the grid-metering impulsing arrangements, due consideration has been given to the above requirements by the British manufacturers. Although no doubt other and better methods will be evolved, the following, which have been adopted, were the best available at the time: (1) Cam-operated contactor; (2) commutator; (3) gravity-operated contactor. Of the four types of grid meters, two are fitted with cams, while the commutator and gravity device have found favour on the other two types. It is difficult at this stage to criticize these methods fully, but some of the disadvantages may be indicated.



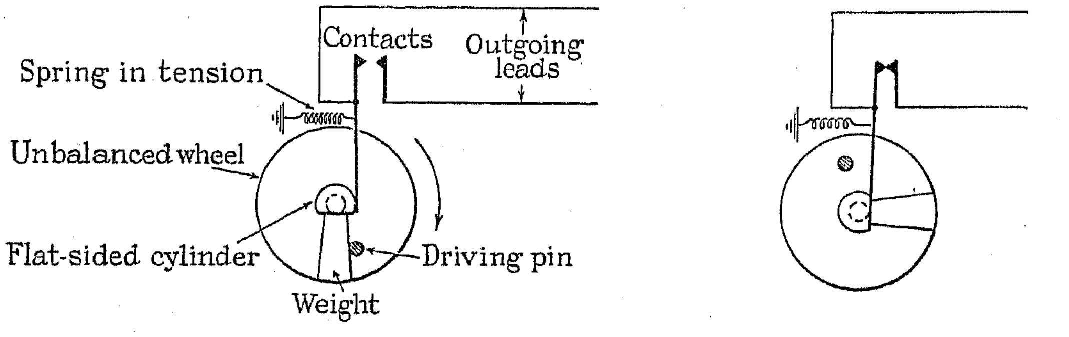
(*a*) (*b*)

FIG. 4.

Cyclic irregularity will be produced on the meter by the gravity- and cam-operated contacts, although with careful design this can be reduced to a minimum. Fig. 4, (*a*) and (*b*), shows the two cam-operated devices. A certain amount of difficulty has been experienced with both types, and the contact springs have been strengthened to avoid vibration trouble. The gravity device is shown in Fig. 5. This method has also given trouble in service and has been modified, but difficulty with the contacts is still being experienced. The remaining method in general use is the commutator. Meter engineers with past experience of commutator meters will be prejudiced against this method, but as contact is only made (not broken) at the commutator, its use in such circumstances is fully justified. It has none of the drawbacks of the cam-operated devices, but both the commutator and the brushgear require careful designing. Initially the brushes used were too light, but these have all been replaced by a heavier type and no trouble has since been experienced. A brush-tension tester which has been evolved by the manufacturers makes it possible to set the brushes on the commutator with the correct tension. After carefully standardizing a meter it is wrong in principle to make adjustments to part of the mechanism unless the limits of possible error can be guaranteed beforehand, or unless the mechanism can be adjusted to operate exactly as before.

All the grid meters are fitted with ratchets to prevent reverse running. The position of this ratchet is important and it should, wherever possible, act on the main spindle. If it does not, the meter may make several revolutions backward before being stopped by the ratchet device. With such an arrangement, under floating conditions impulses may be transmitted when the meter is turning in the reverse direction. Cases of this nature occurred in practice with some of the earlier meters, and quite a large import demand has been registered by the meter oscillating on forward and reverse power. The difficulty was overcome by redesign of the ratchet device.

Consideration must be given to two points in the design of an impulse summation equipment, namely, frequency of impulses and accuracy. To determine the frequency at which impulses should be transmitted it is necessary to consider the life of the transmission contacts. Properly-designed contacts having to break very small currents should be capable of transmitting not less than 10 million impulses during their useful life. For maximum accuracy the number of units transmitted per impulse should be as small as possible, while to obtain the longest life the opposite should be the case. If the number of units transmitted per impulse is large, there is the greater danger of impulses being included in the wrong period of maximum demand, the maximum error occurring when one complete impulse is included in the wrong period.



(a) Contacts open.

(b) Contacts closed momentarily.

FIG. 5.

It is possible to predetermine the limits of accuracy with which the maximum demand can be transmitted for summation purposes. Assume that each impulse shall not be greater than 0·25 per cent of the full load of the circuit concerned. This will be indicated on the maximum-demand dial as 0·5 per cent of the maximum possible half-hourly demand. Thus during each half-hour at full load 200 impulses will be sent, representing 1 impulse each 9 seconds. This seems a reasonable rate of impulsing and it is interesting to consider the life of the contacts and mechanism under these conditions, assuming that the circuit is operating at full load continuously. In 1 year there are 31×10^6 seconds, corresponding to $3 \cdot 5 \times 10^6$ impulses. If, therefore, the useful life of the contacts is 10^7 impulses, this gives approximately 3 years' continuous operation at full load. If allowance is made for the periods when the load is light or when the circuits are dead, with this rate of impulsing a life of 6 to 8 years will be obtained. More frequent impulsing than 1 in each period of from 5 to 10 seconds will lead to excessive wear of the contacts, inaccurate impulsing, failure of the associated mechanism, and high maintenance costs. This, in fact, has been the experience of at least one of the meter manufacturers in connection with metering installations where a high rate of impulsing was specified in order to obtain extreme accuracy.

A definite conclusion having been reached as to the rate of impulsing for satisfactory operation, two questions remain to be decided, namely: (*a*) Should all meters in the same installation transmit the same number of units per impulse? (*b*) Should the number of units per impulse be graded in proportion to the full rated load of each circuit?

As regards (*a*), if the number of units per impulse for each installation is constant, the rate of impulsing will vary with the rated load of the circuits, leading to unequal wear on the contacts and inaccuracy due to the greater possibility, on small circuits, of impulses being included in the wrong period, and also to the fact that on small circuits each impulse will represent a much greater proportion of the demand on the particular circuit. A numerical example will, perhaps, explain the position. Suppose that in one station a 50 000-kW and a 12 500-kW circuit are operating in parallel and that the rate of impulsing is the same in both cases, being equal to 0·5 per cent of the half-hourly demand at 50 000 kW; this will represent 2 per cent of the rated load of the smaller circuit. If it is assumed that a full impulse is lost in each circuit or transmitted in the wrong period, the maximum error will be 500 kW on the combined demand of 62 500 kW, or 0·8 per cent. If the impulsing were correctly graded the possible error would not exceed 0·5 per cent at this demand, and at lower demands the error would be proportionately increased. In the above case only two circuits have been considered; there are numbers of stations in the country, however, which are equipped with from five to eight generators of relatively small capacity when compared with the rating of the grid circuits, and if a specific case is worked out it will be found that considerable errors may be introduced. Although these may not exceed the limits of accuracy of commercial metering, they exceed the limits of what has now come to be known as "grid accuracy" in the measurement of kWh.

With graded impulsing it is possible to guarantee on all equipments uniform accuracy comparable with the accuracy of the kWh meters. Stated briefly, the objects attained with graded impulsing are uniform accuracy, uniform wear, and reliability throughout the whole of the metering equipment.

TABLE 6.

Details of summator	A	B	C	D
Meter contactor	Commutator	Cam	Gravity-operated	Cam
Impulsing	Graded	Constant	Constant	Constant
Type of receiver	3-wire double-coil, rotary armature	3-wire 2-coil, oscillating armature	2-wire single-coil, attracted armature	3-wire 2-coil, oscillating armature
Consumption of coils	5-6 VA	1·5 VA	1·75 VA	1 VA
Transmission from receiver to demand indicator	Ratchet driven by armature	Ratchet driven by armature	Ratchet driven by cam levers in resetting	Electrical contact from armature
Method of summation ..	Differential	Differential	Direct drive controlled by motor-driven camshaft	Electrical impulses controlled by motor-driven rotary switch
Method of subtraction ..	Reverse drive through differential	Reverse drive through differential	Reverse drive through differential	Cancellation of equal positive impulses
Length of demand-indicator scale	250 in.	180 in.	120 in.	30 in.
Method of resetting demand indicator	Gravity	Spring	Spring	Spring
Type of recorder	Ink printometer	Carbon-paper printometer	Maxigraph	Carbon-paper printometer

Only one of the manufacturers has adopted graded impulsing on the grid metering equipment, although in each individual installation the number of units transmitted per impulse is properly proportioned to the largest circuit in the installation. It is probable that, in the future, graded impulsing will be demanded on individual circuits as well as on each installation.

SUMMATING EQUIPMENT.

The remainder of a mechanical summating equipment on multiple circuits is external to the kWh meters, which have no additional work imposed on them other than that due to the initiation of each impulse. The summation is carried out in one mechanism, each element of which acts as a receiver of impulses from its associated kWh meter. The summator therefore comprises a number of receiving elements connected mechanically or electrically to the maximum-demand indicator and its printing or recording device.

RECEIVING ELEMENTS.

Each kWh meter is associated with an impulse-receiving element fitted in the summator meter, and it is of interest to consider the methods adopted for the reception of impulses and for checking and passing them on to the demand indicator and printometer or recorder. Four different types of summators have been installed on the grid, and these have been classified for comparison purposes in Table 6. For convenience it will be advisable to describe these individually, referring to the other types where similarity or differences occur.

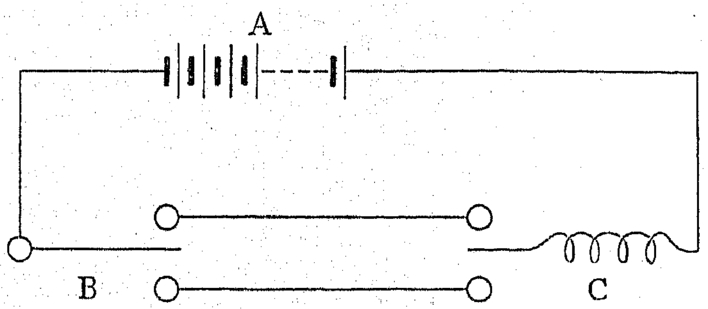


FIG. 6.—Corridor switching arrangement.

A. Local battery supplying power to operate summator elements.
B. Equivalent diagram of commutator attachment fitted on transmitting meter (single-pole 2-way switch).
C. Equivalent diagram of receiving element fitted on summator element (single-pole 2-way switch).

In Type A, contact is made in the kWh meter by means of a commutator, and each contact representing one impulse is passed on to a double-coil receiving element fitted with a rotary armature. The connection between the commutator and the receiving coil is made by means of the familiar 3-wire corridor-switch arrangement, as indicated in Fig. 6. Consideration of this diagram will show that contact is always made in the meter and broken at the receiver, so that there is no sparking at the brush contacts. The rotary armature in the receiver is connected through a ratchet device to the receiving-element driving spindle, which is geared at one end to a differential shaft in the summator and at the other end to a counting train and index. If impulsing is being maintained correctly this index should agree with the meter index and any faulty action of the impulse receiver is immediately indicated by a difference in the index reading at this point. Fig. 7 shows the complete receiving element. It is extremely simple, perfectly definite in action, and can be relied on to give perfect results over long periods of time with scarcely any maintenance beyond occasional oiling.

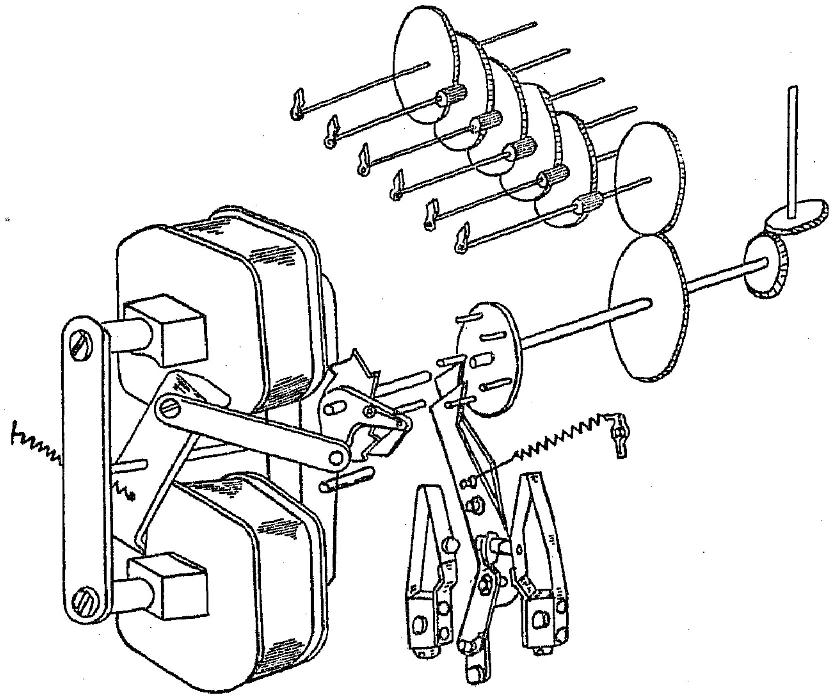


FIG. 7.

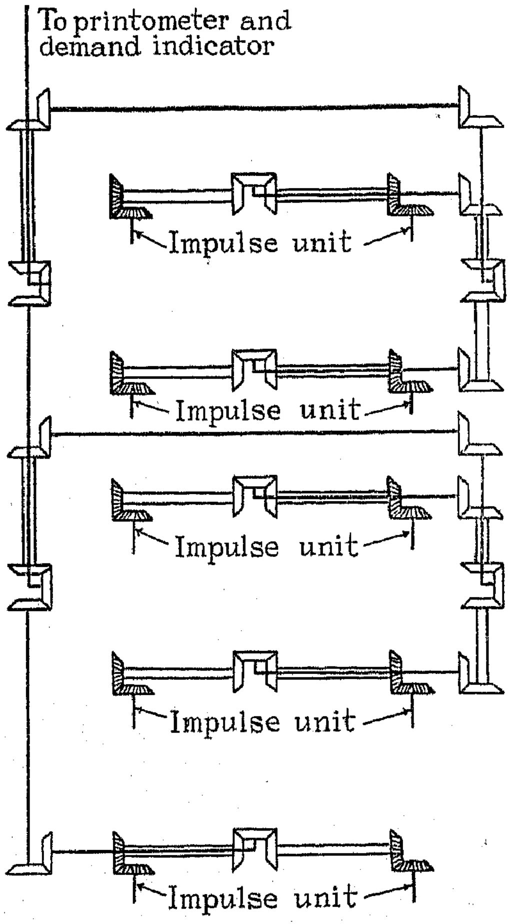


FIG. 8.—Gearing of a 10-element summator.

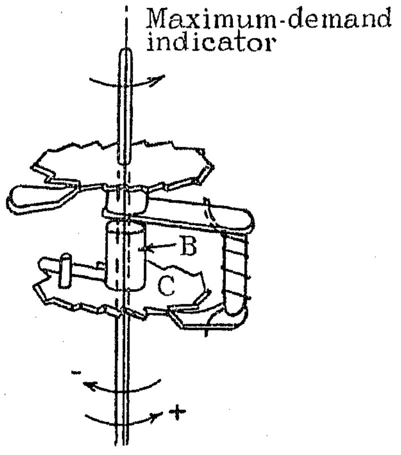


FIG. 9.

In order that the impulses received in the summator may be added correctly the receiving elements are differentially connected together in pairs, and these pairs are again connected together through a differential as pairs of pairs. The method is indicated schematically in Fig. 8. There is theoretically no limit to the number of receiving elements which can be connected together in one summator in this way. Considerations of size and weight, however, limit the number of elements in practice to 12 or 14. There are several 12-element summators working satisfactorily on the grid.

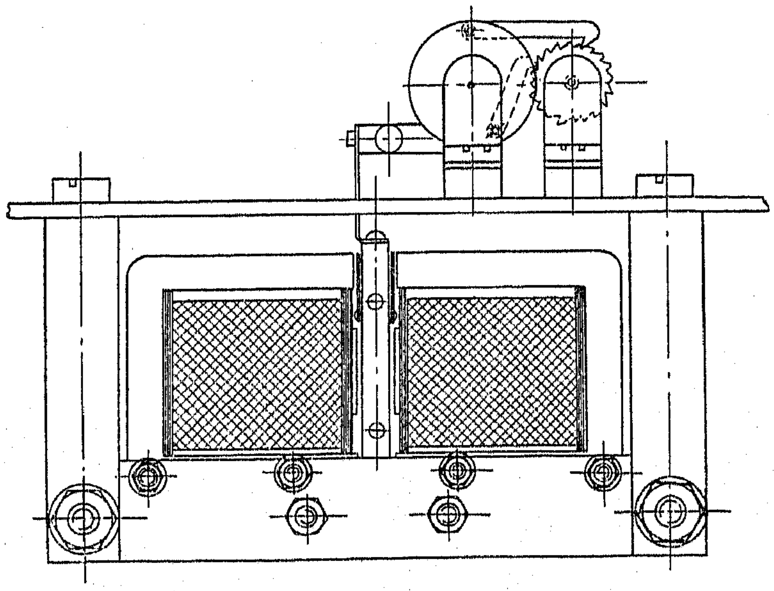


FIG. 10.

In the differential type of summator, negative impulses introduced into a local demand summator by power exported from a generating station are included in the summation by connecting the receiving-element gearing to operate in the reverse direction. To enable this to function correctly the main driving shaft to the demand indicator is split, and a unidirectional device (shown in Fig. 9) is incorporated. This enables the negative impulses to be taken up and traded mechanically against the positive impulses being transmitted to the demand indicator.

With the Type B summator the impulses are initiated in the meter by means of the cam contactor shown in Fig. 4(*a*), and these are received on the 2-coil oscillating-armature element shown in Fig. 10. The impulses are passed on from the oscillating armature through two ratchets, one being arranged to rotate the ratchet wheel in a positive direction for one movement of the armature and the other to maintain the positive rotation when the direction of the armature is reversed by another impulse. Contact is broken at the meter, but sparking is prevented by resistances connected across the contacts and shunting the gap. The operation of this receiving element has proved satisfactory in practice, although it has not the perfect record of the Type A receiver.

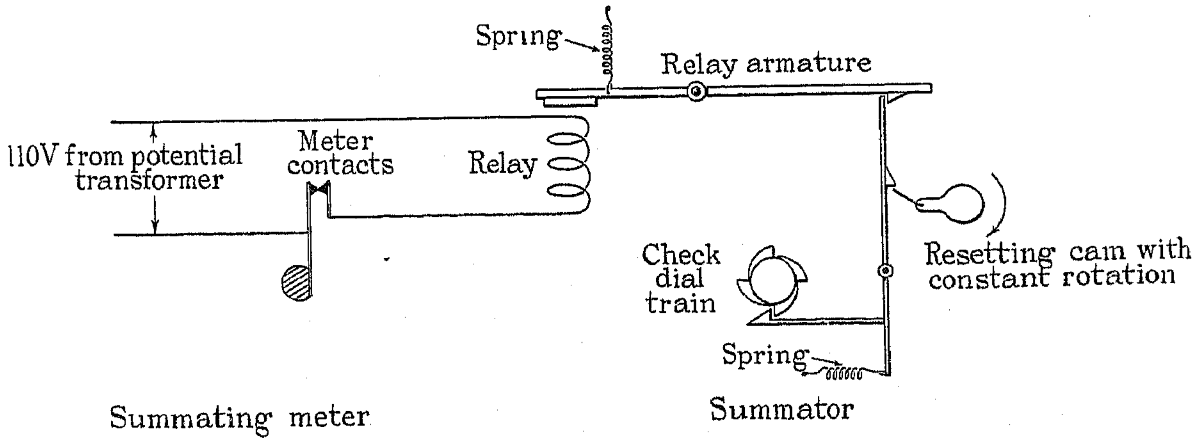


FIG. 11.

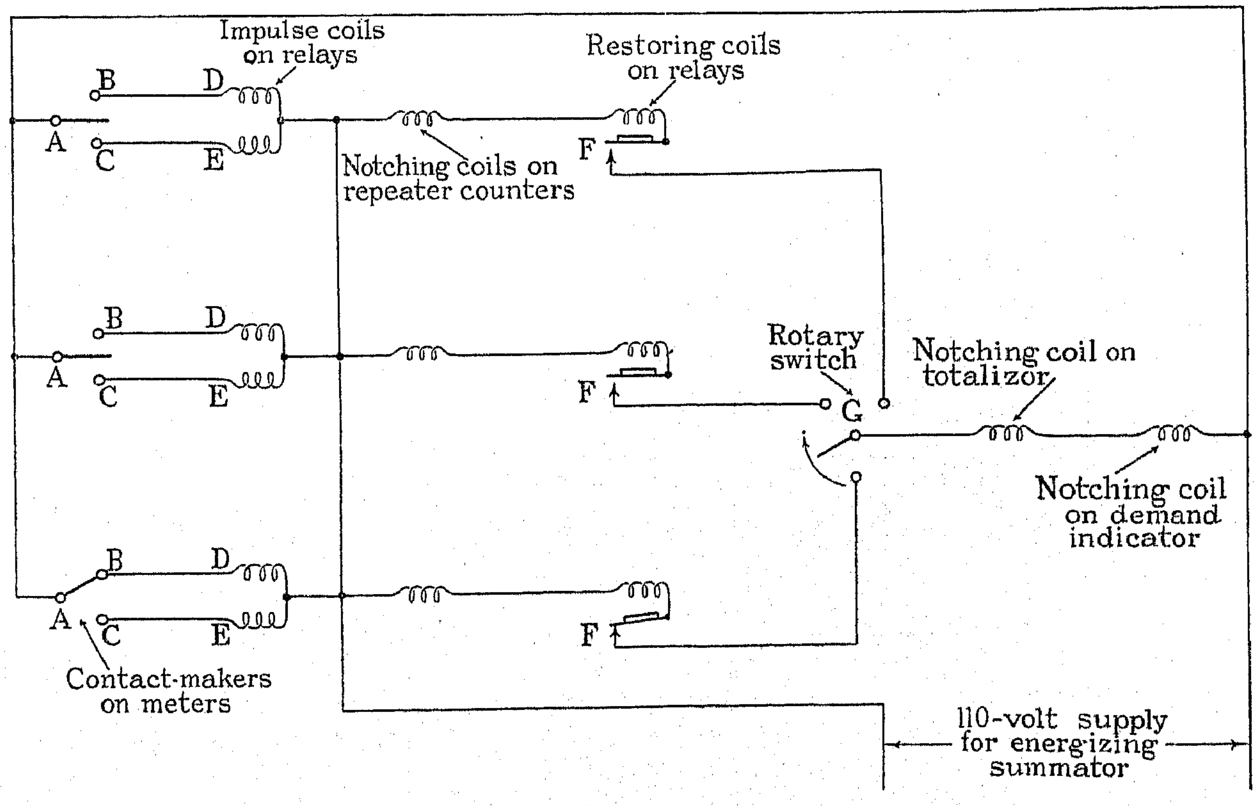

Impulse coils on relays
Restoring coils on relays
B
D
A
C
E
F
Notching coils on repeater counters
B
D
A
C
E
F
Rotary switch
G
Notching coil on totalizor
Notching coil on demand indicator
B
D
A
C
E
F
Contact-makers on meters
110-volt supply for energizing summator

FIG. 12.

From the receiving element to the demand indicator the Type B summator is similar in design to that already described, the summation being carried out differentially. The majority of the summators on the grid metering equipment are differential summators, and when it is considered that the number of circuits which can be summated in this way is only limited by size and weight and that no trouble has been experienced over a period of at least 3 years, the differential method must be classed as the best and most suitable for the purpose.

In the Type C summator each impulse is sent out from the meter by means of a gravity contactor (shown in Fig. 5). The receiving element consists of an armature operated through a single coil by each impulse from the meter. From the diagram in Fig. 11 it will be seen that the operation of the armature releases an arm which is connected to a ratchet wheel. This arm is reset against a spring by means of a motor-driven camshaft, and during the resetting period the impulse is passed on to the summator. As all the ratchet wheels on the receiving elements are directly connected on the same shaft the arrangement must be such that no two impulses shall arrive during the same period. This object is attained by staggering the cams at 90° from each other and arranging the speed of the camshaft and rate of impulsing so that not more than one impulse can be given on each receiving relay during one revolution of the camshaft. It follows that only 4 elements can be connected together in one bank. The number can be increased to 8 by arranging a second bank of 4 on the opposite side of the camshaft operated by the same cams. In this case the ratchet-driven shafts are connected through a differential so that the sum of the rotation of the two ratchet shafts can be obtained. Where it is desired to subtract the power registration in certain circuits such as auxiliaries or export circuits, one of the relay banks can be connected for receiving negative impulses, and the main shaft will then register the difference between the two banks.

An index is provided to register the total number of positive units transmitted, and, provided impulses are not lost in transmission, the index total should agree with the sum of the readings of all the meters connected to the summator. Individual counters are also provided on this type of summator so that it is possible to see at a glance whether the complete apparatus is functioning accurately.

The Type D summator is of particular interest as it is the only one which carries the method of electrical impulsing right from the integrating meter to the demand indicator and recording mechanism. It is similar in some respects to that already described under Type C, and operates on a system of time-controlled impulses. The diagram of electrical connections is shown in Fig. 12, and a study of this will indicate the method of operation. Each impulse is initiated in the integrating meter by means of a cam-operated centre contact which oscillates between two side contacts so that two impulses are transmitted for each revolution of the cam. The impulse receiving element, a diagram of which is shown in Fig. 13, consists of a double-coil relay with a vertical oscillating armature. On receipt of an impulse this armature moves to the operating side and by its movement releases the armature of the restoring relay. When the restoring relay armature drops, contact is made in a circuit connected to a rotary contact-maker which controls the transmission of all impulses between the integrating meters and the summator. The rotary switch is provided with a series of contacts, each one of which is connected to a restoring relay, and as the rotary switch makes contact an impulse is transmitted through three notching coils, one operating a repeater counter, another operating a totalizor, and the third the demand indicator. The action of the rotary switch is similar in all respects to that of the camshaft in the Type C summator, but the impulses are electrically controlled, whereas in the camshaft type the control is mechanical. The speed of the rotary switch and the rate of transmission of impulses must be chosen so that only one impulse arrives per contact on the rotary switch. If two impulses arrive between two contacts on one transmission circuit, then one will be lost and the summation will be inaccurate.

Where auxiliary or export circuits are connected to the summator, negative impulses will be received from the meters on these circuits. These are subtracted from the positive impulses by means of a subtraction relay, which is so arranged that it opens the circuit through the totalizor and demand-indicator notching-coils but not that on the repeater counter. In this way the next following positive impulse is lost in the total; but the passing of the positive impulse resets the subtraction relay, causing the next positive impulse to be included in the total. It is thus seen that negative impulses are traded electrically against positive ones, and so subtracted from the total transmitted.

Like those on the Type A and Type B summators, the repeater counters act as a check on the impulses transmitted from each integrating meter to the summator, and, provided that no impulses are lost, the repeater counter should always be in step with the meter index.

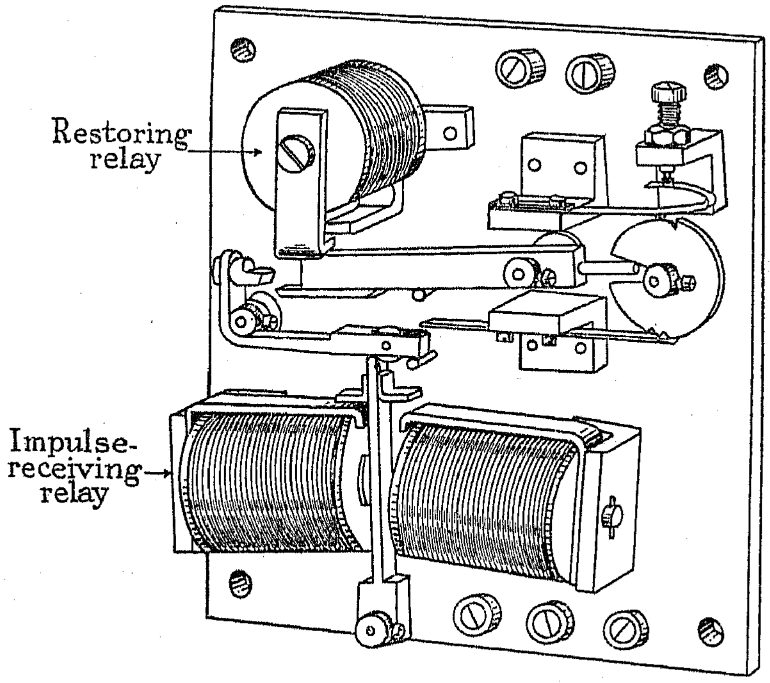


FIG. 13.

The idea of impulsing electrically throughout appears to be sound in principle, and in its conception reflects great credit on its designer. Owing to the number of contacts inherent in this type it is essential that these should be liberally designed and that special precautions should be taken to reduce the effect of sparking. Experience shows that the percentage of faults on the Type D equipment is highest on the impulse units.

Maximum-Demand Indicators.

The summators which have been described are all fitted with Merz-type maximum-demand indicators. Two scales are provided on the Type A indicator, the pointers of which are related like the minute and hour hands of a clock. The large pointer is driven by the long-scale gearing shown in Fig. 14, and the small revolution-counter is geared down from it. During the resetting period the gearing to the long-scale pointer has to make several revolutions; this is effected by means of a cord and weight.

On the Type B indicator a similar long-scale arrangement is provided, but the indicator pointer is geared up from the revolution counter, which is driven direct from the summator. This method is not so satisfactory as the Type A, and a special spring device has been fitted to overcome backlash. The resetting of the mechanism is performed by a spring.

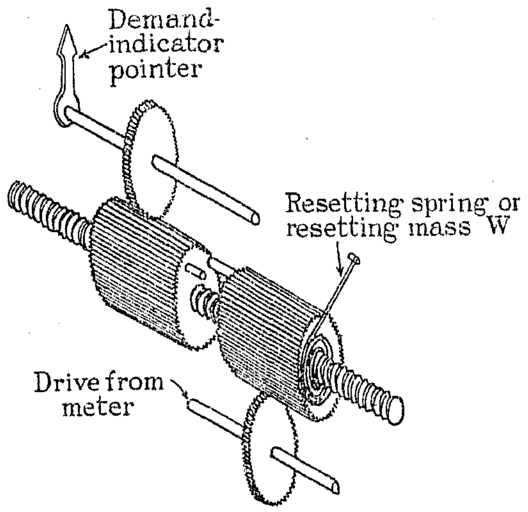


Fig. 14.

The effect of gearing the revolution counter down from the indicator pointer is obtained by a different method in the Type C indicator. Reference to Fig. 15 will indicate the arrangement adopted; it is subject to backlash errors, owing to the large gear ratios involved. The indicating dial in this case is smaller than any of the others, but owing to careful design and finish the accuracy is not appreciably less.

There is nothing of special interest in the Type D indicator. The pointer makes one revolution only for full scale, and the length of this is increased by increasing the diameter. The same result could have been obtained by improving the finish of the scale and pointer.

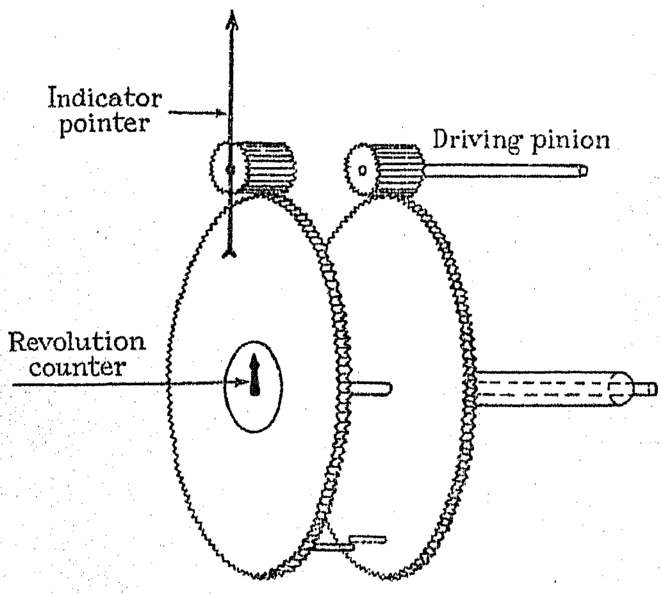


Fig. 15.

Demand Recorders.

On the grid metering three types of demand recorders have been adopted. Two of these types, A and B (Figs. 16 and 17), are printometers, while the third, Type C (Fig. 18), is a maxigraph. On the Type D metering equipment the same printometer has been fitted as with Type B metering. As there are only two makes of printometers a comparison is of exceptional interest, and although a printed record of the half-hourly demand is made in both the design and method of operation of the printer is radically different in each case. The comparison between the two methods is summarized in Table 7.

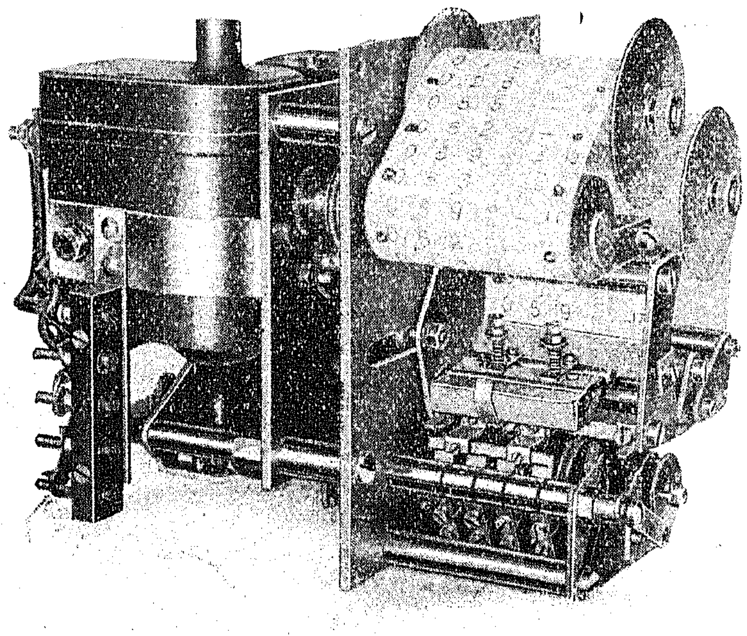


Fig. 16.—Type A demand recorder: ink printometer.

Table 7.

Details of printometer	Type A	Type B
Relation to summator	Incorporated	Separate case
Drive from summator	Geared to main shaft	Impulses from summator
Record made by ..	Ink	Carbon paper
Interval between refills	3 months	3 months
Length of chart, days	70	40
Number of figures ..	5	4
Relative indication of right-hand figure, kW	10	100
Length of visible record, hours	1½	8
Visibility from outside	Poor	Good
Method of operation	Chart brought to type wheels	Chart brought to type wheels
Method of printing ..	Chart rolled on type wheels by rubber roller	Chart stamped on type wheels by finger pads
Operation of printometer	A.C. or D.C. motor	A.C. or D.C. motor

In making a comparison between the two types of printometers it must be stated that, while neither has given perfect operation, the Type B printer has up till quite recently given the better service. The initial record of the Type A printer was not very satisfactory, the main cause of dissatisfaction being the illegibility of the printed records. By close co-operation between the manufacturer and the meter engineers it has been possible to improve the operation to such an extent that equally good results are now being obtained from both.

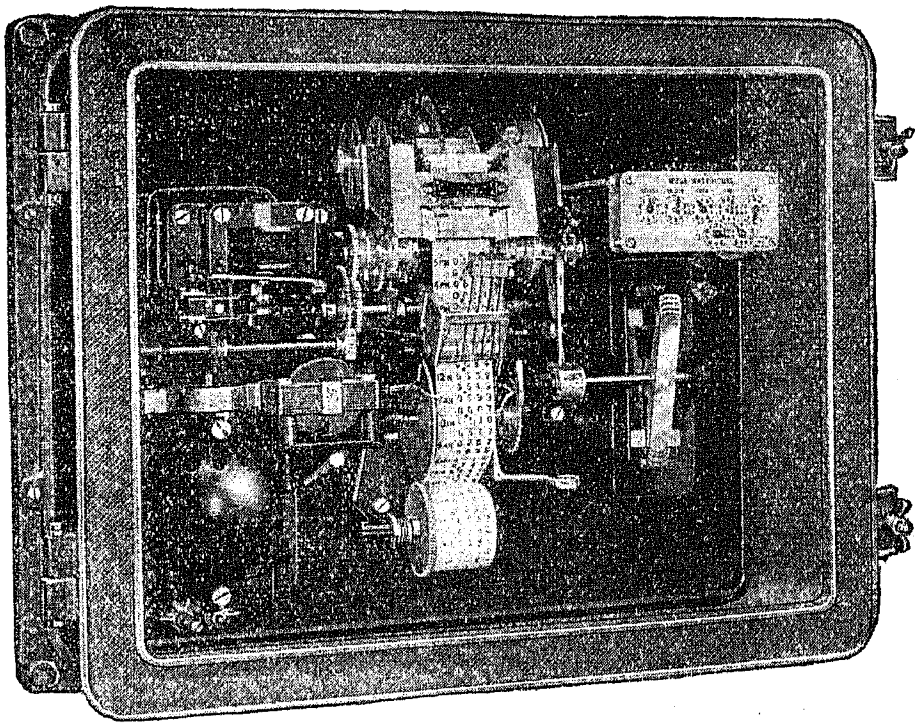


Fig. 17.—Type B demand recorder: carbon-paper printometer.

In comparing the actual demand records of the two printers, reference must be made to the method adopted. In the Type A printer (Fig. 16) the record is made by rolling the chart over the type wheels, which are previously inked by a felt roller. The original arrangement for feeding the ink to the felt roller was by means of wicks from an ink trough to a spreader roller. In many cases this gave perfect results, but these were exceptions, and it was found impossible to get consistently good printing on all installations. In the Scottish area this method has been discarded entirely, and hollow felt rollers, called Casson rollers, after the engineer who first suggested their use, have been fitted throughout. These rollers are filled with a hypodermic syringe, and it has been proved that one filling will last for 6 months. To make certain of consistent results, however, they are refilled every 3 months. The Type B printer (Fig. 17) is arranged with a carbon-paper ribbon passing in front of the chart, which is placed in front of the type wheels. At the instant the record is made four fingers stamp the carbon-paper ribbon and the chart on to the type wheels, and a consistently clear record is obtained. It seems possible that this method may lead to rapid deterioration of the type wheels, but sufficient experience has not yet been obtained to enable the average life to be stated.

A further interesting point in the Type A printer is the provision of a vernier wheel on the right-hand side which gives the equivalent of 5 figures in the record, against 4 in the Type B printer. In the type A printer the type wheels change over from 10 to 100 and from 100 to 1 000 gradually, leading to what is known amongst meter engineers as split figures on the record. This appears at first sight to be a drawback in comparison with the Type B printer, where the figures change quickly. Consideration of this feature, however, will show that a slight inaccuracy in the change-over may cause large errors in the record. When the meter engineers or clerical staff become accustomed to reading the split-figure chart like a meter index, it is found that greater accuracy can be obtained.

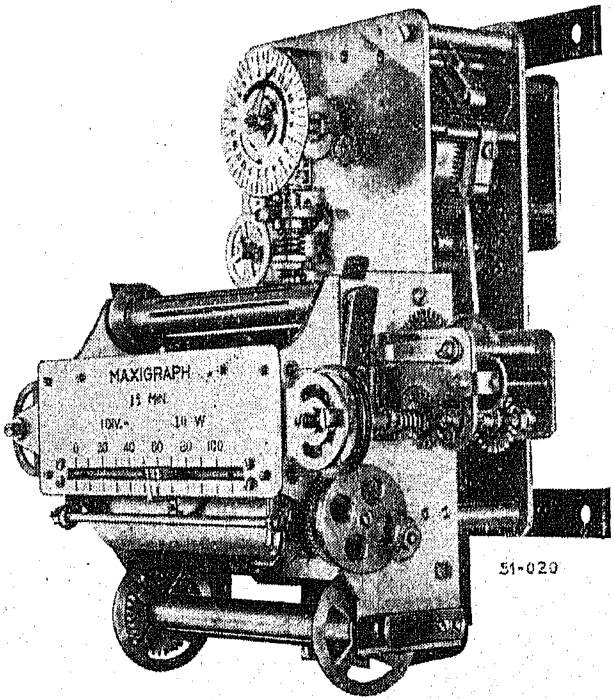


Fig. 18.—Type C demand recorder: maxigraph.

Maxigraphs.

The Type C summation equipment is provided with a recorder in the form of a maxigraph (Fig. 18) with an effective width of the chart scale of 160 mm. Provision is made by suitable subdivision for accurate reading down to 0·1 per cent of full scale. This is good, provided the maximum demand approximates to full scale, which is by no means always the case. There are many cases where a full scale of 10 times the maximum demand is required, so that the error of the record is then of the order of 1 per cent of the actual maximum demand. To this error must be added the possible errors of measurement, so that the maxigraph type of recorder and demand indicator suffers in this respect by comparison with the other types.

The method of making the record is interesting in that no ink is required. The record is made by means of a silver marking wheel rolling on specially prepared paper during the resetting period, so that the mechanism is clear of the paper while the demand is being registered.

The maxigraph type of recorder has definite advantages in that it gives a pictorial record of the load curve and enables the maximum demand and the time of its occurrence to be read off rapidly and conveniently. Its accuracy is, however, in the author's opinion insufficient for accountancy purposes.

METER RECORDS.

Accounts are adjusted by the Central Electricity Board every month, which means that each meter must be read at least once per month, as near the end of the month as possible. As the records are required for operation as well as accounts, it is more convenient to have shorter reading periods. It has been recognized that the consumption of electricity forms an excellent guide to trade conditions, and weekly records are much more convenient for recording results in graphical form. In unattended stations it would prove impossible to take readings more often without a considerable expansion of staff, and at present weekly and monthly readings are the general rule.

In attended stations the metering equipments are generally larger and more complicated, and an endeavour has been made to have the readings taken regularly at 12 midnight. This ensures that the impulsing and retransmission of impulses is checked every 24 hours, and no serious error can go undetected for a long period. Such close checking entails the willing co-operation of the station staffs, and so far no serious objection has been raised to their performance of this duty where they have been asked to carry it out. The reading of meters and recording of results make a comparison unavoidable and lead to faults being reported within 24 hours.

Maximum-Demand Readings.

In all the larger stations maximum-demand recorders are installed in addition to the demand indicators. At the end of each month, therefore, a regular routine must be followed in order that the maximum demand for the month may be agreed upon between the Central Electricity Board and each authorized undertaker. In the case of kWh meter readings serious errors are not likely to occur, or if they do they are easily corrected; when the demand indicator is reset, however, the record is lost. A representative from both parties must therefore approve the reading of the demand indicator as near the end of the month as possible, more particularly as the indicator reading is in most cases used for accounts. The recorder charts have also to be changed as soon after the end of the month as possible, although this can, if necessary, be left for several days. This operation is best performed by the meter staff, as expert inspection and adjustments can be made to the meters and summators during a visit to change charts. If doubt is cast on the indicator reading it can be checked on site by the meter representative who changes the chart.

The fact that the chart records are retained means that reference to the demands can be made for any half-hour during the month of account, and the charts are filed in the District Office for that purpose. Generally the chart records are not used for the purpose of determining the maximum demand for accounts, and the indicator reading is taken unless the coincident demands are required for two or more stations. In such cases, unless automatic summation is provided for by means of pilot wires, reference to the chart records must be made.

For determining the power factor at the time of maximum demand, the chart record must be used at least once each year. The maximum demand is obtained on the indicator, the time of maximum kW demand from the chart kW record, and the corresponding reactive-kVA demand at this time from the reactive-kVA chart. From the two readings the power factor can be worked out.

The chart readings, particularly the kW records, have a value quite apart from accounts; the majority of authorized undertakers and station engineers are now commencing to use the printed records for load curves. Application is made regularly for charts to be sent to the authorized undertakers' offices for this purpose in cases where a bulk supply is given from selected stations, but where possible it is now common practice to log the half-hourly demands on the station log sheets, which have been amended for this purpose. This arrangement has decided advantages over the previous practice of logging indicated readings, and it also provides a continuous check on the operation of the demand indicators and their associated recorders.

ROUTINE MAINTENANCE.

It is recognized in all branches of engineering that the best method of maintenance is prevention, and the meter maintenance programme should be drawn up with this aim. The service required from the meters, impulse units, demand indicators, and printometers, is exacting, and it is only by regular inspection and adjustment that satisfactory operation can be obtained. The average generator meter may have to record between 50 and 100 million units per annum, resulting in approximately 2 million impulses in the same period. Each demand indicator must reset correctly 16 800 times each year, and the associated recording device must print the half-hourly demand the same number of times. From a consideration of these figures it will be seen that if the performance is to remain satisfactory for a long period of years without failure, the adjustments must be regularly checked.

All apparatus is tested in the manufacturers' works before the design is passed for manufacture, but such tests do not always show up weaknesses. Where a series of operations has to be initiated and completed by meshing of gear wheels the operations may be satisfactorily performed a very large number of times without failure, and the apparatus may so function during the works tests. Where large metering equipments are installed, in isolated cases an occasional failure, say, once a year, may not be considered abnormal. This single failure, however, is 100 per cent per annum, and in an area in which 200 summators are installed would represent 17 faults per month, so that the apparatus would be regarded as unsatisfactory. If the recorders and summators are regarded as separate units, then in an area with 200 summators and recorders 34 faults per month might be expected. If the meter faults are added to this it is certain that the full time of two meter engineers would be occupied in clearing the faults, as, owing to the areas involved and the distances to be covered, each fault takes practically one day to clear.

It is found in practice that faults are due to three causes, namely, imperfect design, wear, and incorrect adjustment.

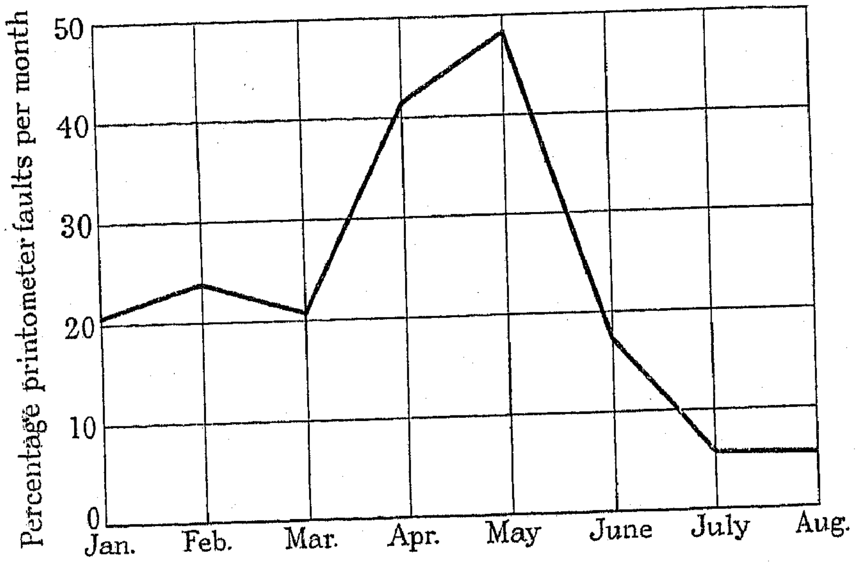


Fig. 19.

Design faults invariably show up as recurring faults, and it has been found possible by recording and allocating all faults under section headings to locate the parts of the equipment which are giving trouble. It is not difficult, proceeding along these lines, to determine the cause of the trouble and thereafter to make satisfactory modifications. The curve shown in Fig. 19 gives an idea of how the percentage number of faults on printometers, for example, may be reduced by design modification. The peak in this curve occurred during the period in which modifications were carried out, and the lower portion of the curve reached in later months is what might be expected from a section of the equipment which is operating satisfactorily.

Trouble has not yet been experienced due to wear, and it is not to be expected that trouble from this cause will develop under a period of 5 years.

The metering equipment is made up of a very large number of moving parts, each one attached to its neighbour by some mechanical arrangement which is liable to get out of adjustment, and unless the adjustments are exceedingly critical it is usually possible to locate such incipient faults and prevent them by a regular programme of inspection. Experience has shown that the individual adjustments will remain satisfactory for definite periods of time, and by tabulation of the necessary adjustments on a suitable time basis a satisfactory programme of inspection can be arranged. The programme given below has been found satisfactory for most of the impulse metering equipments on the grid. This programme is based on regular monthly, 3-monthly, 6-monthly, annual, and biennial inspections. The monthly inspection is in most cases a superficial examination of the entire metering equipment, whereas the inspections which are carried out at longer intervals necessitate detailed examinations and adjustment, if necessary. Monthly inspections can be carried out at the time of changing the charts, and by arranging a suitable form of monthly report it can be made certain that none of the points has been overlooked. The following programme has been in operation in several of the districts for some considerable time and has proved very satisfactory in practice.

Monthly Inspection.

(1) Alignment of meter readings and impulse units.

(2) Inspection of meter contacting device.

(3) Changing charts and checking of printometer and clock timing.

(4) Operation of printer.

(5) Operation of resetting mechanism.

Three-Monthly Inspection.

(1) Adjustments on impulse receiving elements, demand indicator, and printometer, checked and reset where necessary.

(2) Carbon-paper ribbons reversed or renewed, or inking rollers refilled.

(3) Resetting operation of demand indicator and printometer checked.

Six-Monthly Inspection.

(1) Adjustment of impulse receiving elements checked and mechanism oiled.

(2) Inspection of all contacts for wear.

Annual Inspection.

(1) Examination of meter contacting-device, cleaning of contacts, and checking of tension.

(2) Examination of meter jewels and pivots, and re-oiling where necessary.

(3) Examination and re-oiling of printometer motors.

Biennial Inspection.

Complete test of all meters against portable substandard.

The smooth operation of an inspection programme such as the above leads to a considerable improvement in the operation of the metering equipment.

It is difficult to assess the number of faults which might be expected on a satisfactory metering equipment. The following limits are suggested from the author's experience, the faults being given on a percentage basis of the individual parts of the equipment per month: Meters, 1 per cent; impulse units, 1 per cent; demand indicators, 1·5 per cent; printometers, 5 per cent. It is very doubtful whether these figures can be improved on in any metering equipment. A large number of the faults which occur in practice are minor ones and have little effect on the meter records.

FAULT REPORTS.

It is essential that as far as possible the faults which do occur on grid metering equipments should not prevent correct records being obtained for accounts purposes. Meter fault reports should, therefore, be drawn up in such a way that the meter engineer can tell, from a perusal of the fault report, whether the fault is serious or not, and whether it requires immediate attention. At least 75 per cent of faults do not in any way affect the accounts. Check meters are provided in all cases where kWh are measured, and in the event of one meter being faulty a sufficiently accurate record is obtained from the corresponding check meter. Impulse-unit failures only become serious at the time of maximum demand, and in many cases this is only required during the winter period. Demand-indicator and printometer faults during a large part of the time are not serious and can be repaired at leisure. Owing to the fact that a single case of failure in the impulse units, demand indicators, or printers, may affect the metering equipment at a time when the record is important, arrangements must be made for faults to be reported immediately so that they can be attended to without unnecessary delay. In all the districts a meter fault-report form is in general use. Faults are reported by telephone to the control engineers, and the meter fault-report forms are filled up and passed to the meter engineer within a very short time of the fault being reported. The details of the circuit and meter involved and the effect of the fault on the metering equipment are incorporated in the fault report, so that the meter engineer has full particulars and can tell at a glance whether immediate attention is required. In this way cases where agreement is reached otherwise than by direct reference to the meter records are reduced to a minimum, and the author cannot recall any case in his area during the past year where the results given by the meters have not been accepted for accounts purposes.

METER TESTING.

It was originally intended that in the event of the grid meters requiring adjustment they should be removed from site and returned to the manufacturers' works. The drawbacks to this proposal are obvious, and instances have occurred where, after meters have been returned to the manufacturers' works for re-adjustment and been re-installed, it has been shown that the meter adjustments have altered during transport.

All districts are provided with two portable sub-standards for test purposes, and test points are fitted on all metering panels. Should suspicion fall on any meter, a portable sub-standard which has previously been calibrated against some agreed standard is connected in at the test points. Should the meter adjustments prove to have altered, re-calibration of the meter will be necessary. Many meter engineers still consider that the best method is to remove the meter in question and have it re-calibrated and re-adjusted against sub-standards in a suitable test room. As a result of experience, however, the author is doubtful whether this is the most satisfactory method. The objection has been put forward that it is impossible to calibrate a meter on site owing to the fact that test conditions cannot be maintained constant. This, in the author's opinion, is not a rational objection. Suitable test sets have been provided in all the grid districts so that meters can be tested on site against portable sub-standards. These are fed through one of the meter potential-transformers, and it is possible to check the meters at specified loads and power factors. During such a test the sub-standard and the meter are working under similar conditions, and provided these are maintained within reasonable limits an absolutely constant load is not essential. By testing in this way against a portable sub-standard, it has been found possible in practice to make adjustments on an inaccurate meter, resulting in agreement with the original test certificate, and on varying loads with the corresponding check-meter, equal to that obtainable before the meter lost accuracy. It is therefore seldom necessary to remove meters from site in order to re-calibrate.

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E. FAWSSETT and G. E. MOORE: "Apparatus and Methods for Accurate Maintenance of Large A.C. Energy Meters," *ibid.*, 1931, vol. 69, p. 647.

E. W. HILL and G. F. SHOTTER: "Current-Transformer Summations," *ibid.*, 1931, vol. 69, p. 1251.

DISCUSSION BEFORE THE METER AND INSTRUMENT SECTION, 2ND FEBRUARY, 1934.

Mr. E. Fawssett: The author considers that grid metering equipment faults can be regarded as satisfactory if they do not exceed certain percentages per month. If these figures are calculated per annum, they become rather alarming: namely, meters 12 per cent, impulse units 12 per cent, demand indicators 18 per cent, and printers 60 per cent. This means that each printer is expected to give trouble every year and a half. On a system embracing most of one corner of England there are some 2 000 large polyphase meters installed, and most of them have to operate under very much more adverse conditions than the grid meters. The statistics show, however, that the faults on the meters do not exceed 2 per cent per annum. Demand indicators and time switches claim a much larger percentage, and I do not regard these components as highly reliable. By contrast with them, the faults on our system of summation by averaging recorder are negligible. One large colliery combine on our system has 18 separate points of supply, and the simultaneous maximum demand on these is obtained by each having an averaging recorder. Not one of the latter gave a single wrong reading throughout the whole of last year, and their construction makes them capable of very high accuracy. These instruments have no backlash, and give readings correct to the order of 0·5 per cent of full scale. If the percentage of faults which the author quotes as what he hopes to get eventually really represents the best the contact systems can ever achieve, then I think that they stand condemned. It would have been far better to have installed a properly thought-out scheme of electrical summation; if this had been done, the individual meters could have been just as accurate as now. The conditions under which high accuracy is necessary are favourable because the summation is only required for demand, and can be achieved as described in the paper by Messrs. Hill and Shotter.* Where different voltages have to be combined, the averaging recorders on each voltage group can be combined clerically. A slightly greater latitude can, if needed, be allowed in accuracy. Such a system gives practically fault-free performance, and is preferable to the supposedly higher accuracy of the present grid metering system. The latter is expensive to install and, I fear, to maintain.

Mr. Wilfred Holmes: As I have been responsible for the design of Type B equipment, I wish to confine my remarks to this system. Reactive-kVAh meters are compared in Table 4. They all reverse on leading power factor. The Type B sine meter will run reversed at the correct speed when the phase rotation is reversed. It may be simply corrected by reversing the potential wires at the terminals of the meter. The consulting engineers wisely specified that each meter should have ratchet and pawls fitted, so that no meter can run backwards. Turning to the question of transmission contacts (page 189), I do not agree with the author's remarks about the drawbacks of cam-operated contacts. In the Type B cam-operated contact, shown in Fig. 4(*a*), two rollers run in jewel bearings with no measurable friction. The large silver contacts are subject to a good pressure, owing to the leverage, and the additional torque on the cam spindle is so low, even at the peak of the cyclic curve, that it does not interfere with the starting current of the meter. The author says on page 190 that properly-designed contacts should be capable of transmitting 10 million impulses during their useful life; this is a fair estimate, and I wish to state that many of the Type B contacts have already exceeded it. I am pleased to see the author's favourable report on the Type B printometer (pages 195 and 196), but I hope that he is wrong where he predicts rapid deterioration of the type wheels. He cannot mean chemical deterioration, as no carbon paper touches them. They are machine-cut figures of hard gun-metal. They work at the slow rate of 48 prints per day, which represents an average of 4·8 prints per figure per day. The light rubber pads strike by momentum, and not by spring pressure. On Table 7 the author compares two makes of printometers; there is so much difference in their design that he must have had some difficulty in listing them together. The Type B printometer is shown to a disadvantage in Table 7, under the headings of "Number of figures" and "Relative indication of right-hand figure." By the arrangement of changing the figures, which do not necessarily change over uniformly, the impulse received is printed accurately, and there is no need to have a vernier scale. For instance, if the impulse received was 7, then the printer would be arranged to change over in the order of 7, 14, 21, etc. The first wheel would have the figures cut in the following order round the rim: 7–4–1–8–5–2–9–6–3–0. Any odd number, decimal, or fraction, could be transmitted, and when the number happened to be a repeating decimal, for instance, it would become extremely simple. It would, of course, be necessary to cut the figures on the first wheel a little smaller. Take the example of $1\cdot\dot{4}2857\dot{1}$. The first wheel disc would be cut with the figures $1\cdot\dot{4}2857\dot{1}$, $2\cdot\dot{8}5714\dot{2}$, and so on; at the nearest convenient whole number (e.g. $19\cdot99999\dot{9}$) it would be necessary to print 0020·000000 in order to get an accurate base line. The printed chart would appear thus:—

Accurate base	$\lvert 0000\cdot000000 \rvert$
First impulse	$0001\cdot\dot{4}2857\dot{1}$
Second impulse	$0002\cdot\dot{8}5714\dot{2}$
Seventh impulse	$0009\cdot99999\dot{9}$
Eighth impulse	$0011\cdot\dot{4}2857\dot{1}$
Fourteenth impulse	0020·000000
900 impulses	$1285\cdot\dot{7}1428\dot{5}$

Notice that these would be only 4-wheel discs, just like the standard. Now, this printometer would be no more accurate than the one with a single figure, but the author would have to give it the credit in Table 7 of being a 10-figure printometer. At present, Type B printometers are only made with three types of figures on the first wheel disc, i.e. 1, 2, and 5 (base). This gives a choice of 0·1, 0·2, 0·5, 1, 2, 5, 10, 20, etc., kW per impulse. With only four wheel discs it is found that, should the time switch cut off or change over just before the impulse, the worst case of inaccuracy would be 0·1 per cent. All impulse-type machines, whether vernier, straight-print, or chart, would have a similar change-over error. As regards grading of impulses, I would point out that, in Type B metering, impulses are both graded and proportioned by being re-transmitted; there is a storage spring barrel in the summator which stores up the impulses, and should the impulses come in together they are stored and given out more uniformly.

Mr. O. Howarth: The metering equipments described in the paper are all operating in reasonably favourable situations, generally in or about the power stations, where the conditions are not usually as bad as those met with on the premises of industrial consumers. The author points out that the same accuracy is not required on generator circuits as on the Board's circuits, owing to the fact that on the latter there may be floating conditions and the meters may have to register very light loads. Yet I notice from Table 2 that, with 5 per cent of the full load, 2 per cent error is allowed on both the Board's circuits and the generator circuits. Turning to methods of measuring reactive kVAh, I notice that Type D uses phase-to-neutral voltage from the voltage transformers. The oscillogram, Fig. A, shows the wave-form of the phase-to-neutral voltage of a 3-phase bank of voltage transformers. It would be interesting to know what steps are taken to ensure correct wave-form when these voltages are used. I am surprised at the attitude the Board have taken with regard to auxiliary circuits. In one case with which I am acquainted, where the current-transformer errors were known, the meters were calibrated as though the current transformers had no errors. With regard to diamond jewels, our experience of these on 4-element meters over a long period of years has been quite satisfactory. No signs of wear have been noticed. I do not agree with the statement that the 4-element meter will be entirely superseded in future by the simple method of paralleling the two sets of current transformers at the meter terminals; because, unless those current transformers are in circuits which are themselves in parallel at that point, they are not dealing with a common voltage. It is not legitimate to parallel current transformers on to a 2-element polyphase meter unless the voltage is common to both circuits. We use a combination of the two methods to meter a h.t. supply delivered along four feeders terminating on two different sections of busbar. The arrangement is shown in Fig. B. If there were only two feeders, one on each section of busbar, the current transformers could not legitimately be paralleled on to a 2-element meter, because if the section switch was open the two busbars would not be at the same potential, and the measurement would not be correct. I should like to know what the C.E.B. do if the same maximum demand occurs twice in the month, the power factor being different in the two cases. Have the Board adopted any cheaper method of measuring the power factor at the time of maximum load for small supplies? It must be expensive to install recording mechanism in order to measure the power factor on a supply of about 500 kW and, in view of the terms of the Act by which supply undertakers have to pass on the Board's charges, with certain additions, they may have to make the same measurement for relatively small supplies. In a station of the type indicated by G2 in the Board's Metering Memorandum, G1 metering has been installed. Can the author indicate the reason for this departure?

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* *Journal I.E.E.*, 1931, vol. 69, p. 1251.

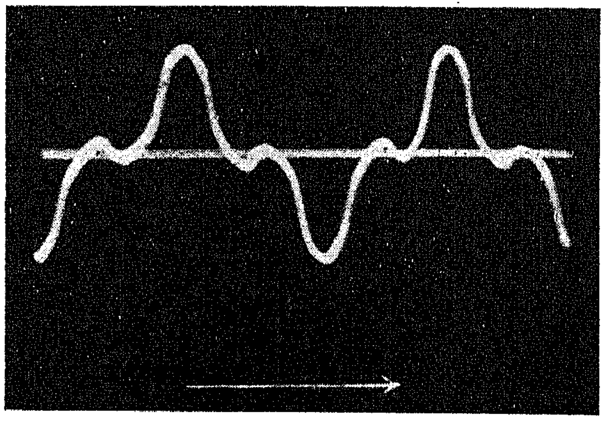

Fig. A.

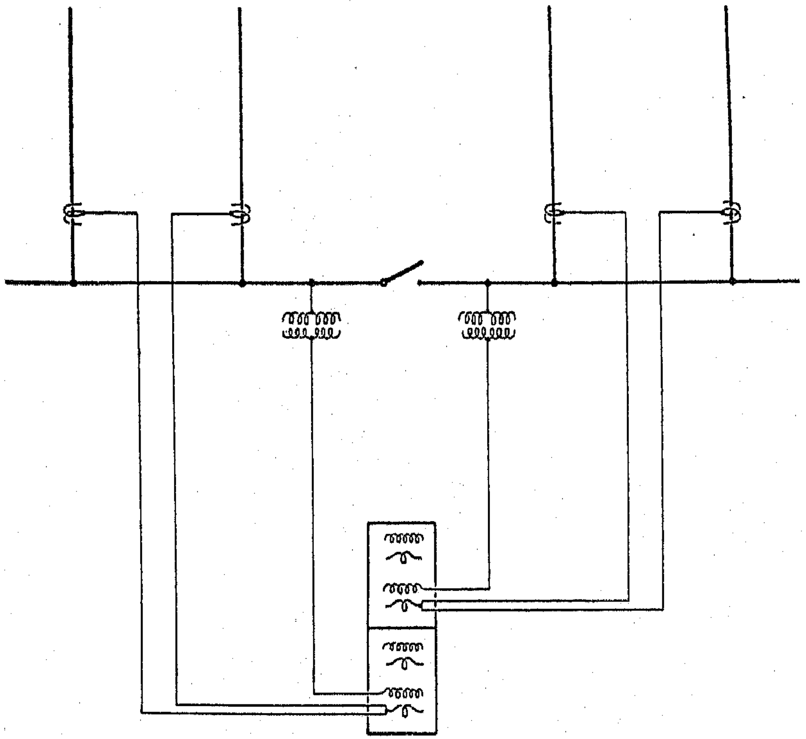

Fig. B.

Mr. G. A. Cheetham: The grid metering scheme is probably the most accurate scheme of its size in the world, especially in view of the fact that with a summation meter the accuracy on the summation clock (on the law of averages) should be considerably less than the maximum error on the meters operating it. The problem of solving this difficulty has involved a considerable amount of development work for British engineers, and four solutions of the one problem have been satisfactorily produced. The final results, therefore, reflect great credit on British meter engineering. The author states that an impulse unit should operate satisfactorily for 10 000 000 impulses. This figure has been exceeded in actual test figures, and the results have been entirely satisfactory for considerably more impulses than have been mentioned. Years ago, when I was designing instrument apparatus, in dealing with problems involving contacts I always tried to find a solution based on mechanical rather than on electrical devices. There has been a great change in the design of contacting apparatus since that time, and contacting devices can now be relied upon quite as well as any mechanical devices, and for some purposes, such as this, they are essential. I only need to instance the automatic telephone, which gives fewer wrong numbers than did the manual system, to show the reliability of contact mechanisms. In addition, a great deal of successful contact work has been done on ignition systems for motor-cars. The correct contact pressure and wiping action must, however, be employed to give satisfactory contacts. I have seen two pieces of clean silver in perfect contact, without wiping action, successfully insulated against 110 volts, and no circuit could be obtained through them. One of the best wiping contacts is the slip-ring, which provides a continuous burnishing and wiping action. This was one of the reasons which led the company with which I am connected to use a so-called commutator for the contact portion of its meter. It is not really a commutator, however, but a corridor switching arrangement, because it cannot break a contact. The device has worked very successfully. I should like to point out, in conclusion, that the ingenious maximum-demand gearing shown on page 198 was designed by Mr. O. Howarth.

Mr. J. S. Buckley: With regard to the standard used in meter testing, I should like to mention the portable standard which I described at the recent discussion on the paper by Mr. J. B. Lees.* This enables an accurate test to two decimal places to be readily made, and any necessary adjustment can be effected on the spot. With regard to the test points, is the author's test block of the type by which one can clear the meter completely, the current transformer being put automatically in short-circuit? If so, then by merely using the proper rotating standard it would be possible to test the meter exactly as in the test room. There would thus be no need to remove the meter. As far as the artificial load is concerned, one can get the necessary supply from the station from which one carries out the test. Turning to the question of records, the cards which we used are based on a typical American system of colours. The colour of the card indicates whether the particular meter to which it belongs is tested every 3, 6, or 12 months, and 2 or 4 years. The Americans call them "history cards." All the details of the meter are recorded on them, and they are filed in such a manner that one can locate the test in any period. A smaller index card enables one to locate the correct meter card immediately, and thus find out when the meter is again due for testing. The test certificate which we use appears to be complicated, but it is not really so. When filed by meter number, like the history card, it affords an excellent and readily available record.

Mr. E. A. Webb: I should like to make a few remarks about the Type D equipment. On page 189 reference is made to the contacting device on the meters, and it is suggested that the commutator is superior to the cam-operated device. Both commutator and cam have been tried extensively on the Type D equipment; there is little, if anything, to choose between the two, and as preference was expressed by the purchasers for the cam-operated type this was finally adopted. From experience I should say that the life of the commutator-type contactor would be shorter than that of the cam type. Type D equipment operates with alternating current, which is much less severe on the contacting device than direct current. On page 193 the author states that differential methods of summating are the best and most suitable for the purpose. It is doubtful whether this statement is justified, as it is not borne out in practice. An electrical method of summating, as used in Type D and illustrated in Fig. 12, has definite advantages from the maintenance point of view, since all the components are made of interchangeable units, which can, if necessary, be replaced on site in a few minutes without interfering with the operation of the rest of the summator. It is suggested on page 194 that special precautions are necessary to reduce the effects of sparking. This is not the case, because the equipment operates from an a.c. supply, and the effect of sparking is very much less with an a.c. than with a d.c. supply. It is a well-known fact that a switch will interrupt a much larger load on alternating current than on direct current. Few, if any, contacts have been renewed on Type D equipment on this account. Furthermore, the volt-ampere consumption in the impulsing circuit is considerably less in the Type D than in the others, as will be seen from Table 6. It is stated on page 194 that, owing to the number of contacts in Type D equipment, it is essential that they should be liberally designed. As a matter of fact, they are liberally designed, and a comparison of Figs. 12 and 6 will show that the same number of contacts is provided as in Type A equipment.

Mr. A. J. Gibbons: It is a pity that the Central Board had such implicit faith in all their contacting gear that they installed only one maximum-demand indicator per metering equipment. It is true that they employ a printometer; but, as this is operated from the demand indicator, it is not of very much help. If a meter or its contacting gear fails, or the receiving mechanism misbehaves, the maximum demand is unfortunately not obtainable from the equipment put in to measure it. Perhaps it would have been wiser if the Board had duplicated the maximum-demand equipment and saved the cost of doing this by using rather more simplified methods of determining the power factor. The company with which I am associated has used a variety of summation equipments for maximum-demand measurement. Current summation apparatus has been employed by us quite frequently. We have about 90 of the averaging recorders referred to by Mr. Fawssett; they are, however, of the older pattern, and we have had some trouble with them, but as the result of certain small modifications which have been adopted our faults are becoming fewer and fewer. I have experimented with an early form of the author's Type C equipment. It has given reasonably good service, the chief trouble being the contacts, which require very careful setting and adjustment if reliable service is to be obtained. The Type C chart mechanism is quite good, but I have a preference for the printometer when it comes to determining accounts, because its indications are more definite. We are also running a Type B equipment, which, apart from one or two minor troubles, has given good service. We have had one or two cases of double printing, caused, I think, by a fault in the time switch. The equipment is fitted with duplicate 4-way summators, and the agreement of the maximum-demand indicators on a load of between 60 000 and 70 000 kW is well inside 0·5 per cent on a very "jumpy" traction load. The author voices a doubt with regard to the resistance to wear of the type wheel. I should like to refer to our experience with a similar apparatus of much cruder form, namely the workmen's time recorder. Although the type wheels of these instruments are generally made of comparatively soft metal, and are subjected to very severe usage, they easily survive 5 years' service. These type wheels have to stamp through a thick card with a very heavy hammer. I therefore do not anticipate any trouble in connection with metering printometer wheels. I am not in favour of some of the maintenance and testing arrangements which the Board are proposing to adopt. I still feel that the best place for carrying out adjustments to meters, particularly large meters, is in the quiet of the test room rather than on a busy switchboard.

Mr. H. B. Nield: The most important considerations of summation apparatus are accessibility and maintenance. I think there is little reason for not coming to a very early conclusion on this point, after closely examining all the apparatus we have before us this evening. I consider that the question of forecasting the life of metering equipment should have been omitted from the paper, especially seeing that printing wheels in the Type B gear are so very reliable. The author does not mention that the printing hammers are rubber-faced, and therefore do not receive severe shocks. I have met with no failures of printing wheels in 4 years' operation, representing 16 000 000 contacts and some 60 000 half-hourly printings. With reference to the Summary, I agree that the electrical impulse summation system was wisely selected for the Central Board's use. I do not altogether agree, however, that many stations would have been improved by the adoption of graded impulsing from meters to summators. Why wear out all the contacts at the same speed? I think a summator gear with graded impulsing would not be so easily interchangeable as a summator with complete equipment for a certain scheduled rate of contacting. I want to dispel an impression which Mr. Cheetham gave with regard to silver contacts; Captain Cohen's recent paper* indicates that silver contacts have been chosen for light duty after several years' experience. Turning to Table 3, for the Type B meter, the weight of the rotor should be 20 to 25 g, and not 81·5 g, because the magnetic suspension carries some 70 per cent of the weight of the rotor. It might have been mentioned in the Table that in Type B the contactor is operated by rollers which are mounted in jewel bearings, as distinct from Type D. The Table might have been enlarged somewhat, so as to include the maximum and minimum kWh per contact, and also accessibility to contacts for cleaning and removal. In Type B one can change the contacts bodily without fear of not being able to replace similar friction on the meter. On page 186 the author states: "A notable feature of the Type B meter is the introduction of double driving elements and a duplicate braking system on each disc, in order to obtain balanced torque on the meter spindle." I think this might be better expressed as a "balanced thrust." Turning to page 187, the author mentions that reversal of phase rotation gives incorrect registration, which is a decided disadvantage. I do not agree that there is any disadvantage in this, because, if wrong-phase rotation exists, connections can be altered to suit this condition. With regard to electrical summation, the author omits to mention the extra cost involved by a potential selector relay, as compared with the other method of summation. Finally, experience of contacts on Type B equipment has been exceptionally good. I can quote, with the assistance of the Central Board readings, one meter passing 30 000 000 contacts satisfactorily without any known trouble—the average is 6·5 kW per contact for about 3 years. At the bottom of page 190 it is recommended that each impulse shall not be greater than 0·25 per cent of the full load of the circuit concerned. If the author would reduce this figure to 0·05, it would better represent working conditions on many Type B equipments operating in South-East England, and under these conditions I am sure the author would not suggest graded impulsing for all integrating meters. Graded impulsing between summators has been used on the Type B equipments wherever necessary.

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* *Journal I.E.E.*, 1934, vol. 75, p. 41.

Mr. H. S. Dransfield: The method of power-factor measurement described on page 185 is interesting. Many supply authorities measure power factor by means of a sine and cosine meter and modify their charges on the average power factor so obtained. In practice this does not necessarily give the same result as the Central Board's method, and it may eventually have repercussions on supply authorities' tariffs and methods of measurement. I notice that Class B accuracy is specified for potential transformers: this can admit of errors of 1 per cent in ratio and 30 minutes in phase angle. Potential transformers having very much greater accuracy than this can be easily obtained, and it seems an anomaly to tolerate larger errors on the potential transformers than on the meters themselves. Many meter engineers feel that, so far as the meter itself is concerned, the most important problem is that of the bearings. If greater reliability could be obtained, meters would run for many years with very little attention. I note that some of the Board's meters are supplied with diamond bearings while others have synthetic jewels; serious errors will occur if these are not reliable. It would be interesting to learn more about the nature of the oil used for the footstep bearings, and whether this changes in the course of time. It is surprising to note that the tolerance for the generator meters is greater than that of the others, and yet it would seem easier to obtain an even higher accuracy on the former as their load conditions are better. Even a comparatively cheap temperature-compensated meter will give excellent results on such a load. I congratulate the author on his scheme of routine testing, which indicates that he is aware of the possibilities of error arising in such complicated apparatus. I think much valuable information will be gained by these tests, and they should prove useful to meter engineers generally.

Mr. A. H. Gray: Referring to the auto-transformer mentioned as Type B in Table 4, is the accuracy impaired when the secondary burden is altered? If so, trouble will occur when these meters are checked on site, by the introduction of check instruments into the circuit. Dealing with the various types of transmitter gear, I notice that the Type C in Table 6 employs a 2-wire impulsing circuit in conjunction with a gravity-operated cam and a motor-driven camshaft. If the feeder system is floating, it seems possible for this cam to remain closed, which in turn will allow the motor in the summator to transmit impulses to the demand indicator continuously and hence provide erroneous readings. I should like to know whether such a condition has been witnessed under site conditions, and, if so, what precautions have been taken to overcome the trouble. The author mentions that cyclic irregularity in cam-operated contacts can be reduced to a minimum by careful design; but, turning to Table 3, one is struck by the significant fact that all those meters employing cams have much higher torque than the one meter using a commutator type of contact, and this suggests that the cam does impose rather more load than the commutator. In my opinion, in the case of the cam the small working distances (of the order of 20 mils) might lead to incorrect impulsing due to extraneous vibrations. The next point at issue is the question of graded impulsing; I suggest that if used with the capacities met with in practice, in some cases 15 000 kW down to 2 000 kW, the graded-impulsing method is much more accurate than the standardized method. Only a system employing a mechanically operated printer can use graded impulsing to its full capacity. With such a printer, every impulse which is passed from the various elements to the summator clock is faithfully registered on the printer. When, however, there is an electrical link between the summator and the printer, the impulses can only be passed at a definite rate. The new problem which arises is best illustrated by an example. Suppose we take a 12-element summator with an electrically-driven printer, and 12 similar elements, what should be the rate of transmission from the summator to the printer? If this rate is kept the same as that of the individual receiving elements, to obtain the same accuracy, the transmitter to the printer will operate at 12 times the speed of any one, assuming they are all working at the same rate. If, on the other hand, the rate of transmission is made smaller to reduce wear, the accuracy of the printer will suffer. It becomes obvious, therefore, that any summator employing either standardized or graded impulsing will lose some of its initial accuracy on the printed record if electrical transmission is used between the summator and the printer.

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* *Journal I.E.E.*, 1934, vol. 75, p. 133.

Mr. A. Page: The author omits to mention a host of important operating details; for instance, the paper contains no illustration of the metering elements by which the improved meter performance has been obtained, nor does it deal with the lay-out of typical Type A and Type B stations, the relative merits of alternating current and direct current as an auxiliary supply, and the question whether master clocks should have a mechanical reserve. The inclusion of this information would considerably enhance the value of the paper. Turning to Fig. 2, I find it difficult to follow the explanation of the Type C reactive-kVA meter. It would be useful if the author would illustrate the internal connections in more detail, to show how the vectors are arrived at. This type of meter has the fundamental advantage that standard connections are employed, and, more important still, correct registration is secured even with reversed phase rotation. Of minor importance is the fact that the meter is uninfluenced by frequency variations or unbalance of voltage. On page 188 reference is made to test certificates for meters operating alone and in conjunction with their own current transformers. Even if this provision involves an extra charge the practice is to be strongly recommended in all cases where important meters are concerned, as it enables subsequent re-calibration to be readily carried out in a test room.

I consider the 4-element meter method of summation (described on page 188) to be very clumsy, and not to be compared with that of interlaced current-coils for cheapness. If it is desired to have the two sets of elements distinct it is advisable to mount them on separate spindles driving through a differential a common summation train, but this method is expensive. It has the advantage that the individual readings and demand can be ascertained if necessary. The author states that the accuracy is good " owing to high meter-loading; " I suggest that this should read " if the meter loading is high," as very often an equipment is only run at a partial load and under these conditions the argument does not apply. Before leaving page 188 I should like to refer to the notes on auxiliary circuits. I cannot follow the argument that extreme accuracy on the metering is of secondary consequence, particularly under the poor load-factor conditions with which we are still faced. At the same time I quite see that if, owing to the scattered nature of the auxiliaries, the metering is difficult, then an economic balance must be struck between what is essential and what can be omitted. In the 4th line from the bottom of col. 1 the word " delivered " could be replaced to advantage by the word " absorbed." On page 189 the author states that the ideal method of securing impulses is one which imposes no load on the meter, and that no method of this kind has yet been developed. This remark does not do justice to Mr. Spilsbury's wonderful contrivance, shown at the Physical Society's Exhibition, for the counting of revolutions by means of a photo-electric cell. Whilst Mr. Spilsbury does not claim that his method is suitable for commercial application, I am convinced that it will not be long before a modified commercial product is evolved. Whilst on the subject of impulsing I should like to add a further important desirable feature to the list in col. 2 of page 189. This is that " the contacts should not linger." It was precisely for this reason that the out-of-balance device illustrated in Fig. 5 was evolved, and I consider that it is the ideal method of securing the desired result. The statement (page 189) that it produces cyclic irregularity is of such an academic nature as to be almost hypothetical. If we are to take into account such small variations we should commence by considering the influence of an anti-creep device. Turning to the question of printometers and maxigraphs, I think some of the points brought out by the author are fundamentally weak. We are told in Table 2 that the best accuracy of the metering employed is ± 0·5 per cent. As we have to add to this the errors in the summation and recording mechanisms, the best accuracy we can hope to achieve is of the order of 1 part in 200. Any figures representing closer readings are not in themselves more accurate, and in fact are redundant. Nevertheless, printometer A gives readings to 5 figures, and printometer B and maxigraph C give readings correct to 1 part in 1 000, which is already greater than the accuracy of the originating meter and more than twice the accuracy at even half scale. I cannot follow the author's suggestion that, because some readings are to be taken at one-tenth scale, therefore the maxigraph suffers in comparison with the printometer. Precisely the same arguments apply to the printometer, and under similar conditions its accuracy is correspondingly reduced. It is stated by the author that the maxigraph is of no value for accountancy purposes; I maintain that the maxigraph gives as accurate results as any other system yet devised, and it also gives a pictorial record such as cannot be gathered from a maze of figures many of which have no significance. I should like to refer to the desirability of securing the average power factor at times of kW maximum demand. It would appear that reactive-kVA measurement combined with chart records of kW and reactive kVA are necessary to ascertain this figure. The expense involved in this provision must have been enormous, quite apart from the trouble on such equipments, which, according to the author, amounts to 5 per cent. The fact that these printers are used for this purpose is borne out by the statement on page 199 that printometer faults can be repaired at leisure. As the Central Board are charging the undertakers on the power-factor basis, the undertakers must in turn apply it to their consumers. Consequently we have imposed on us a tariff the metering of which costs nearly £200 per point if the orthodox method is utilized. I have devised a method which secures the same result by the use of standard parts, eliminates the necessity for records, and costs substantially less than two chart recorders. It is rather premature, however, to disclose details of the method at the present stage. A question which is giving equal trouble is that of averaging the demand over 30 consecutive minutes. I would ask the author how the present system came into vogue, and whether the difficulty is simply that suitable apparatus has not been evolved. If as much attention were devoted to evolving a suitable design for securing this end as is being directed towards circumventing it, a solution would soon be found and the new method would become established practice.

Mr. E. S. Ritter: The apparatus which appeals to me in principle is Type D, where the impulses are carried through electrically from one side to the other. The contacts used in this equipment, however, appear capable of improvement. Fig. 11 indicates an a.c. voltage of 110 volts for working a relay; I should have thought 24 volts direct current would have been much more satisfactory. Fig. 12 refers to a 110-volt supply for energizing the summator, and I presume this is an a.c. supply. Telephone engineers have come to the conclusion that a d.c. non-polarized relay can be made cheaply and reliably, and that difficulties occur when one attempts to use a.c. relays. Fig. 12 shows a restoring coil which operates when the mechanically driven rotary switch closes the circuit. In automatic telephone exchanges an electrically driven rotary switch finds a calling line; in the same way the operation of the impulse coil could be made to pass on the indication to its totalizor and operate it. It should also be possible to arrange matters so that, if one circuit is sending its pulses through and another one comes through at the same moment, the second one will wait until the first has completed its operation. Reference has been made in this discussion to Captain Cohen's paper.* In this connection I would explain that the relays now being employed by the Post Office in telephony have silver contacts, and that platinum is used for the heavy-duty relay contacts operating inductive magnet coils. I suggest that silver would be suitable for the relay contacts mentioned in the paper, as it has the advantage of low contact resistance. Sparking on relay contacts can be largely got over by shunting the inductive coil in circuit with a suitable non-inductive resistance, taking about $\frac{1}{4}$ to $\frac{1}{10}$ the current of the coil. Telephone apparatus is arranged nowadays to jack into position. Is there sufficient apparatus in the grid metering system to justify the use of jack-in units, which can be pulled out, tested, and replaced? Contacts should have a pressure of at least 20 g, and should be double. The rubber hammers of the printometers are much more likely to wear out than the type wheels. I should like to know whether the clock mechanisms of these meters are run off the supply; if so, in the event of a supply voltage failure, do the clocks start again automatically? There is a suspicion, in regard to one installation of which I know, that the maximum demand has been inflated by the stopping of the clock.

Mr. H. S. Petch: The few seconds taken for the resetting of a maximum-demand indicator appear to be important, as an appreciable number of kilowatts may be lost in 12 seconds, more particularly if the load is of a variable nature. On a traction supply, a half-hour period may begin with a load of 40 000 kW and end with a load of 80 000 kW. In such circumstances, the resetting period of 12 seconds might involve the loss of registration of 530 kW unless some kind of impulse storage were provided. The practice of compensating for resetting time in the gearing of the indicator pointer appears justifiable only in the case of slowly-varying loads.

Mr. H. C. Turner: Seeing that there are only 3 900 grid metering equipments, would it not have been better if the manufacturers had co-operated and concentrated on a single pattern? Each firm must have spent enormous amounts of money on tools which will presumably not be used again, and a little friendly co-operation would have resulted in the production of a type embodying the best features of all. Was there any objection to such a procedure?

Mr. E. V. Clark (Australia) (*communicated*): I should like to refer to the author's method for determining the power factor at the time of maximum demand, which is set out in the third paragraph of col. 2, page 197. If this truly represents the procedure adopted to determine the power factor upon which accounts are based, it would seem that there is a serious lacuna either in the phrasing of the tariffs in use or else in the mode of interpreting the metering records taken; since with any tariff which takes peak-load power factor into consideration we may expect to find a greater total charge where the peak load is 9 750 kW at a bad power factor than where it is 10 000 kW at a good one. This fact is likely to be of importance in the near future, if it is not at present, seeing that some supply authorities are already claiming that on parts of their systems the peak load is that due to Sunday-morning cooking. Meanwhile it would appear that where a distribution authority has its normal peak round about 0·7 power factor, owing to industrial loads, it might secure an appreciable saving in the amount payable for grid supplies by installing a suitable high-tension water rheostat, to be put in circuit for not more than half an hour each month at time of good power factor, and so adjusted that it should produce, by a small margin, the peak kW load on the system! The rational method of determining peak-load power factor for tariff purpose with the metering equipment described in this paper is surely to ascertain the various power factors at the times of a number of maxima, occurring at various hours of the week, and levy the account upon that maximum which makes the charge the highest. If the tariff expressly states that it is " the power factor occurring at the time of the maximum kW load recorded " which is to be used in compiling accounts, it should certainly be amended.

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* *Journal I.E.E.*, 1934, vol. 75, p. 133.

Mr. S. A. Clarke (*communicated*): It would be interesting to know the author's experience of the maintenance of the impulse transmitting gear used in conjunction with Types B and C of his schedule of meters. My own experience has been that, faced with the problem of designing contacts of sufficient surface area to be reliable without affecting the meter at light loads, the manufacturers have sacrificed one of these factors for the sake of the other. My maintenance records show that most of the faults in Type B have been due to the slowing-down of the meter at light loads by the contacts, while in Type C the trouble has been usually due to faulty contacting. Of the two evils, the latter is the less, so long as contacting failures do not occur on peak loads. It is gratifying to learn from the author's remarks that it has become general practice among meter manufacturers to fit individual repeater dials on the summators. With regard to the storage of impulses in the printometer during the printing period, it is a pity that similar provision was not made for the maximum-demand indicator. The average printing period is from 2 to 8 seconds, depending on the type. During this time the Merz demand indicator, incorporated in the summator in Type B of the author's classification, is inoperative. My experience has shown that with the impulsing gear operating satisfactorily the maximum demands recorded by the printometer and indicated on the Merz indicator are seldom in agreement. The difference is well within the prescribed limits, but appears unnecessary in elaborate metering. From my observations of grid metering in generating stations on the South-East England section, I cannot help thinking that the author's figure of 1 impulse every 9 seconds is exceeded in actual practice. Assuming this figure, the difference between printometer and indicator would be slightly more than ¼ per cent, but in the case of an equipment of similar type, installed by the company with which I am associated, impulses are transmitted to the printometer at peak load at the rate of 10 in 6 seconds. The maximum demand is of the order of 70 000 kW, the resetting period is 15 minutes (traction load), and each impulse is 12·5 kWh or 50 kW. The minimum printing period is 1½ seconds, representing the storage of 2 to 3 impulses. The kW equivalent is 100 to 150 kW, and this is generally the difference observed between the readings of the indicator and the printometer.

[The author's reply to this discussion will be found on page 210.]

Scottish Centre, at Edinburgh, 13th March, 1934.

Mr. N. C. Bridge: The author has perhaps hardly emphasized sufficiently the importance of the metering on the grid. Very large sums of money are involved in the C.E.B. transactions, and the nearest possible approach to absolute accuracy is therefore of primary importance. This is one of the few matters, in fact, in which cost may well be relegated to a secondary place. As an opening to the discussion, there is just one point I should like to mention; we read in the paper of reactive-kVAh meters. We do not, however, speak of kVAh meters as a rule; we call them watt-hour meters, or very often just wattmeters. Could we not call these reactive meters var-meters ? The term VAR is already recognized, and this would seem to be quite an excusable contraction.

Mr. A. Mears: Table 3 gives full details of the full-load torques, speeds, and weights of the discs of the various types of meters, and comparison can be made between the four types on the generally accepted basis of (Torque × 100)/(Speed × weight of rotor) as representing a permanent factor for accuracy. There are considerable differences between them on this basis, and perhaps the author can say whether experience bears out this formula. It is rather unfortunate that the author does not give more information as to the relative values of the diamond and the synthetic sapphire, and it would be interesting to have a definite statement on this point. In connection with summation I should like to ask whether it would be practicable, instead of having contactors on the meter spindle, to intercept the light by means of a photo-electric cell, and thus avoid the slight strain on the meter spindle. Is any difference observed between the readings on the kWh generator meters and the corresponding dials on the summation meters; and do cases occur where the summator readings exceed the kWh-meter readings, owing perhaps to the impulses giving too vigorous an action and pushing on two teeth instead of one? This has generally been a source of trouble with ratchet gear. Referring to page 191, Table 6, and the question of impulsing, although the paper clearly indicates that the graded impulsing method is superior to other methods it is adopted on only one of the four different types of metering systems. There is also a very marked difference in the nature of the demand-indicator scales of the various types. In all the demand indicators the resetting arrangement takes a definite time to operate. Is there any material difference in this respect between the four types, and, if so, how many seconds are usually allowed for resetting? I should like to ask whether the idea has ever been considered of the whole summator gear being held in tension by a spring and the particular tooth being allowed to escape, rather than being notched, with a view to giving more positive action than that of the notched movement. Such an arrangement would also prevent backlash.

Mr. J. Eccles: Was the temperature curve shown in Fig. 1 obtained on a polyphase meter? A limitation of the method of summation in which current transformers are paralleled at the meter terminals on a single series winding is that all the current transformers must be of the same ratio. With regard to graded-impulsing summators, I should like to know how impulses of different values are traded against each other. It would be of interest if the author could indicate the life of meter jewels, and whether there is any advantage in using diamond jewels rather than synthetic materials. Throughout the paper no mention is made of time-keeping, which is quite as important as any other aspect of metering when maximum demands are being measured. It might be replied that the type of clock used does not lose or gain any appreciable percentage amount per half hour. While this may be true, it is possible for the error to be cumulative and thus to shift the time of resetting away from the beginning of each statutory half hour. This effect might be of considerable financial consequence at times of peak load. Perhaps the author will give details of the types of clocks used and the accuracy obtained.

Mr. G. Caton: With regard to the statement (page 188) concerning the limitations of the use of the electrical method of summation, I presume that the limitations referred to are the errors produced by the burden imposed when one or other of the current transformers is idling. Has the idea of disconnecting the idle current transformer, by means of an induction relay, ever been adopted with a view to removing possible sources of error? When circumstances were such that the secondary current was zero, the relay would close an intermediate d.c. electromagnetic relay, which in turn would break the parallel current-transformer connection. Under all other circumstances the induction-relay contacts would be parted; the relay could be made quite as responsive to a flow of current as the metering itself. Greater sensitivity could be obtained by operating the relay from a separate current transformer of lower ratio. The expense involved by the proposed arrangement would be infinitely less than that associated with the electro-mechanical method of summation.

Mr. R. J. P. Green: I should like to ask the author the degree of accuracy obtained from the metering equipment operating from a tertiary winding incorporated in a power transformer. In the Scottish area all the metering equipments were calibrated with their respective current transformers. On the English grid metering schemes the manufacturers' test results for the current transformers were actually employed for the calibration of the meters. Although the routine testing equipments of most firms are reasonably accurate, it seems to me that many inaccuracies can creep in when meters are calibrated with the reported test results.

Mr. J. N. Atkinson: I have had an opportunity of observing one of the grid metering equipments in operation since its installation, and I should like to inform the author that it has kept within the limits of accuracy given in Table 2. In one year alone some of the meters measured nearly 300 million units, and the readings of the main and check meters differed by no greater limit than that stated in Table 2. On page 186 it is stated that in the event of a reversal of phase rotation on the kWh meters the accuracy should still be within the limits prescribed for correct phase-rotation. I should like to know in what manner it is anticipated that this reversal of phase rotation might be brought about after the meter has been calibrated and finally connected in the circuit. I do not agree with the statement that "it is unlikely that a temperature range exceeding 15 deg. C. would be met with in practice." I think it quite possible that such a limit would be met with, particularly in buildings composed to some extent of glazed windows. In view of the fact that the temperature variation outside the station exceeds 50 deg. F., that inside the station might in some circumstances reach the limit of 25 deg. C. Turning to page 188, I would point out that the only justification of summation metering is to measure maximum demand. The addition of a series of units registered on a straight integrating meter can be carried out more accurately and effectively by calculation than by mechanical means. I cannot think that either the Board or an undertaker would accept for accountancy purposes the figures registered on the final dials of the summation meters described by the author. Summation meters in which complicated mechanism is used must be inherently weak. The author remarks that with graded impulsing it is possible to guarantee accuracy uniform with that of the kWh meters. I rather doubt the accuracy of this statement, because the readings of the kWh meters are not always truthfully recorded on the summating equipment. The armature has to move whole trains of gearing pinions and shafts, and in practice parts of these mechanisms get out of order. I should like to emphasize the necessity for accurate time-keeping in connection with maximum-demand readings. The absence of maximum-demand metering on the export equipment for generating stations is presumably explained by the fact that the Board do not purchase on a 2-part tariff basis. In connection with the maxigraph it is stated on page 197 that there are many cases where a full scale of 10 times the maximum demand is required; I am not quite clear as to why this should be necessary. On the same page it is mentioned in connection with meter records that the checking of impulses and retransmissions is carried out over 24 hours. It is quite possible to have errors on two successive days even though an error may be reported the same night; this might also cause great inconvenience if it occurred at periods of peak load. I think that the reliability of the summation equipments can be ascribed to the constant reporting of faults. The author goes on to say that when the demand indicator is reset, the record is lost. I do not understand this statement; does it imply that the printed value is not always trusted?

Prof. S. Parker Smith: The author mentions the subject of the checking of meters, and I should like to emphasize the importance of getting reliable standards. Soon after I went to the Royal Technical College I found work adversely affected because of inconsistent results. The experimental points obtained would not lie on smooth curves, and one obtained absurd results like power factors greater than unity. It is impossible to teach students satisfactorily under such conditions. Great improvement resulted from the purchase of three large electrodynamometer instruments guaranteed to an accuracy of 0·1 per cent. These instruments were carefully calibrated at the N.P.L. under various conditions, including direct current, to permit checking with the standard cell and the potentiometer. In testing meters it is most important to get very steady conditions. For this purpose our meter testing set is driven by a synchronous motor that runs off the grid supply frequency. This synchronous motor drives three machines on the same shaft, two a.c. machines—one for current and one for voltage—and a third one for exciting the a.c. machines. Only by such methods can one expect to get fairly consistent results. Mr. Green has referred to the kind of measurements carried out in makers' works. A maker always has commercial considerations before him, and it may be that his equipment is not of the best and his time is rather limited. In a college these conditions do not hold. Another inducement to install a calibration laboratory at the Royal Technical College was the need for a proving house for this class of work in Scotland. Further, there should be some reliable independent authority to carry out such tests and enable one to check instruments. For this reason it was a great pleasure to me when the Central Electricity Board discovered the Royal Technical College and made use of its equipment.

Mr. D. G. Sandeman: Meters of the type described in the paper are rather clumsy, and it seems to be asking for trouble to provide instruments of this kind to measure power supplies. Would it not be possible to eliminate trouble due to the complicated mechanism by employing some form of chemical meter for measuring power? There is less likelihood of argument arising over a weight of deposited metal than over the number of revolutions of an intricate mechanism.

Mr. D. H. Bishop: I have been very interested to see with what accuracy the grid meters, which were calibrated separately, have been agreeing with each other in Dundee during the last 2½ years. It would be interesting to know how the difference between the units registered as generated and as sold to undertakings on the grid system compares with the estimated losses.

Mr. Andrew Morris: The Central Electricity Board have been responsible for a great expansion in electrical engineering, especially in connection with power transformers. In a less spectacular degree it has affected meters, as is shown by the fact that one firm making a type extensively used by the Board did not produce demand indicators until the advent of the grid. One side issue of this development is the suggestion that supply authorities should purchase certain single-phase meters because " the element is exactly the same as that supplied in the grid meters." There are, of course, other makes which produce results equal to, and even better than, those having this recommendation. The Type B meter has a rather elaborate design with its double driving and braking elements for each disc, and magnetic suspension of the rotor. Has the author found it more accurate than the other, more simple, types? Information regarding the relative costs of maintenance of the various types would be of interest, because simulated life tests on the single-phase pattern of these meters show that differences in performance exist. What system does the Board adopt for checking portable substandard testing meters? Prof. Parker Smith's description of the equipment at the Royal Technical College answers a question concerning the primary standards installed for this purpose. It would be interesting to know how frequently they are made use of.

[The author's reply to this discussion will be found on page 210.]

SOUTH MIDLAND CENTRE, AT BIRMINGHAM, 9TH APRIL, 1934.

Dr. C. C. Garrard: It appears that the requirements of the Central Electricity Board necessarily involve a greater degree of accuracy than has been usual hitherto, since the function of the Board is to effect a saving by sending the current through its own mains on the way to the consumer. It is therefore a question of measuring the difference between two values of a quantity, which necessarily requires greater accuracy than measuring the quantity itself. Does the system of multiple earthing which is used by the Board make any difference to the metering? It seems to me that the Board could achieve a great saving by summating the whole of the energy at one central point, and I should like to know whether they intend eventually to do this. If so, it will necessitate a great many more problems being solved by the manufacturers. I do not understand why the accuracy of the reactive-kVAh meters given in Table 2 is different from that of the kWh meters, because the reactive-kVAh meter working at zero power factor is precisely similar to the kWh meter working at unity power factor. The author mentions that in one case the potential coil of the reactive-kVAh meter is connected to the neutral point. Is there any trouble in this connection due to variation of the neutral-point voltage from that of the true neutral point of the system? While I approve of the system of using a current transformer with a testing winding, I do not see that it is any more accurate than testing on the secondary. In either case the degree of accuracy depends on the care with which the transformer is made.

Mr. E. R. Knight: In the metering equipments shown in the author's slides each circuit comprises a main and a check kWh meter. As only the main meter effects the impulsing to the totalizors and printometers, it would appear that this meter must have an additional frictional load imposed on it, due to the impulse transmitter. The effect of this would naturally be much greater on lightly-loaded circuits, such as " import " or " export " feeders, which for considerable periods, when the generating station is more or less carrying its own load, are working at only a small fraction of their full-load capacities. This seems to be borne out by the fact that on a certain installation the main generator meters are found to read about 0·5 per cent slow on the check meters (these meters run normally at full load), whereas import and export meters, running lightly loaded, show a deficit of some 10 per cent of the actual kWh. I should therefore like to ask the author whether the main meter is compensated for the extra load imposed by the impulsing relay.

Mr. S. F. Hill: I should like to ask of what material the contacts mentioned in the paper are made.

Mr. W. Lawson: If I were asked to design a system of summation from first principles I should instinctively avoid the impulse type, with its complications and its dependence on moving contacts. In this system whatever the circuit meter says is repeated by the summator, whether it is correct or otherwise, so that the summator is in no sense an independent measure of the energy consumption. This constitutes a weakness in the arrangement. Events tend to show that the power-factor requirement of the tariff is generally superfluous, because owing to the effect of the grid lines we are getting leading power factors at the station. Referring to Table 2, the standard of accuracy on low loads is too exacting and calls for unnecessary refinement in the design of the meters, whilst at the other end of the curve higher accuracy than the values specified could easily be attained and maintained. With reference to diamond jewels (Table 3), I have used these with great success in polyphase meters of 50 kW and upwards, but the results on 50-cycle meters are not so good as those formerly obtained on 25-cycle meters. The expression " type of suspension " applied to meters of Types A, C, and D, in the same table is misleading, because the rotor is not suspended but is supported by a spring-seated jewel. I should be very interested to know what sort of results are being obtained with the magnetic suspension, as it does not follow that lightening the rotor will reduce wear unless other factors contributing to wear of the jewel are also eliminated or lessened. A balanced drive should have a beneficial effect. Respecting works tests on meters, I regard it as good practice to test the current and potential transformers separately from the metering system when methods and apparatus are sound and skilled testers are employed; in fact if this is done calibration is likely to be more accurate, because the method is less cumbersome. I agree with the author that it is not necessary to remove the meters from site for testing, there being little chance of the transformers developing errors. The meters can be satisfactorily tested on site by the phantom-load method. The maintenance data and the methods of routine inspection included in the paper indicate that considerable trouble has been encountered in connection with the grid metering equipment.

Mr. R. H. Rawll: It appears that the electrical transmission of impulses from the individual circuit meters to the summating meters depends upon a source of electrical energy. Both direct current and alternating current are apparently utilized for this purpose, since a battery is shown in Fig. 6 and reference is made in Fig. 11 to a potential transformer. From a purely practical point of view, if this source of supply fails the whole of the summator presumably ceases to function. As a d.c. supply from a battery is, of course, not so liable to fail as an a.c. supply, and bearing in mind the extreme importance of these summating metering equipments, particularly from an accountancy point of view, it would be interesting to know which the author considers to be the better method of supplying the energy, and also what steps are taken to prevent failure of the source of supply.

Mr. W. Burton: On pages 198 and 199 the author mentions the testing of meters after installation by means of a rotating sub-standard meter; while this may detect inaccuracies in the meter itself, it will not give a complete test. If the metering equipment can be tested as a whole, other sources of error will be eliminated; and where a small percentage inaccuracy involves a large sum of money, it is well to avoid disputes with the consumer by tests which do not involve disturbing the wiring or connections. An obvious though cumbersome method is to pass current through the primary windings. It may be necessary to provide a primary current of 300, 500, or 2 000 amperes, and although in some instances this may be possible, it is never advisable. Difficult cases are those where the current transformers are slipped over high-tension cables. A more satisfactory way is to use a special test winding on the current transformer. This is a method which, I can assure the author, has been tested many times and is much favoured by those who have to carry out these tests. If a special winding is provided on the current transformer so that 10 amperes through it causes full-load current to flow in the secondary windings, the metering equipment may be checked without disturbing any connection. A loose connection on a meter terminal may cause the meter to read 50 per cent slow, or even fast if it is on a particular phase; and if this connection has been moved in order to insert a rotary sub-standard, the fault may unknowingly have been rectified merely by tightening up the terminal. By passing not more than 10 amperes it is quite possible to carry out a full range of tests on meters *in situ*, and I think that this is much more convincing to a consumer than merely to insert a rotary sub-standard. Many consumers—particularly those of the Central Electricity Board—now realize that current transformers do alter, that turns are sometimes short-circuited, that the potential-transformer fuse sometimes blows, and that such occurrences are not always detected by a rotary sub-standard. I suggest to the author that he should endeavour to obtain the closest possible approach to a full-load test.

Mr. S. H. Hart (*communicated*): I should like to know whether any trouble has been experienced on account of the wear of contacts. On page 190 the author estimates their life to be 3 years when working continuously at full load, or 6 to 8 years at the usual rate of working; yet he advises a 6-monthly inspection of all contacts, which seems to suggest a rapid rate of wear. The rate of impulsing given, namely 1 impulse every 9 seconds, appears to be high. I believe that on some of the equipments the rate is about 1 impulse every 40 seconds. In this area the average output of each generator being metered is approximately 10 900 kW, and if we take the average impulse as corresponding to 100 kW, and assume 1 impulse every 40 seconds, the estimated life of the contacts is approximately 13¼ years' continuous operation. In telephone practice it has been found that a dirty contact occurs once in about 1 000 000 operations if single contacts are employed, and once in 75 000 000 with twin contacts, i.e. two contacts on the same spring. In the case of the figures given above this would represent once in 100 years. Recent Post Office tests have shown that pure-silver contacts have the best life from the point of view of cost, this being about 9 000 000 operations. Tungsten contacts have proved the best-wearing, but rapidly develop an oxide film. In Table 2 the Board's circuits are shown as having a higher degree of accuracy than the generator circuits, and the author states that precision-type current transformers are installed on the former. I should like to know in which areas this applies, as I do not believe it to be general practice. The potential-transformer accuracy is given as Class B, yet the meters are calibrated to within ½ per cent; is it not possible to obtain greater accuracy on the potential transformers? On page 196 the author suggests that rapid deterioration of the type wheels of the printometer is likely. I do not share this view, as the hammer pads are of rubber and the figures of type metal. I am in agreement with the suggestion that the meter staff should change all the charts, as trouble is likely to arise if anybody not familiar with the equipments attempts to do this. I should like to know whether the author considers a fault on the printometer to be very serious when the printed maximum demand differs from the indicated value, if it is known that the latter is correct. Finally, I should like to say that I think several of the difficulties experienced in connection with the grid metering equipment would have been overcome in the earlier stages if there had been co-operation between the meter engineer and the telephone engineer.

THE AUTHOR'S REPLY TO THE DISCUSSIONS AT LONDON, EDINBURGH, AND BIRMINGHAM.

Mr. J. Henderson (*in reply*): It appears preferable to reply to the discussion under six main headings rather than to the various points as they have been raised by individual speakers.

Meters.

The accuracy of the grid metering equipment is referred to by a considerable number of speakers. The importance of accuracy, which was mentioned in the paper, is emphasized by Dr. Garrard and Mr. Bridge, and tribute is paid to the accuracy obtained on two large installations by Mr. Bishop and Mr. Atkinson, after observations extending over a number of years. The relative inaccuracy of the reactive-kVAh meters and the auxiliary meters is mentioned by Dr. Garrard and by Messrs. Howarth and Page; as both these quantities affect a very small proportion of each account, however, the commercial accuracy is really greater than could possibly be attained on the kWh meters. Mr. Howarth must admit that although the limits of error on the generator circuits and the Board's circuits are equal at 5 per cent load, there is a considerable improvement in the Board's circuits between the limits of 10 and 125 per cent load, thus making allowance, as stated in the paper, for lower loading conditions. I have no experience of the formula referred to by Mr. Mears, and, with regard to the accuracy of the Type B meter mentioned by Mr. Morris, no attempt has been made to compare the accuracies of the various types of meters adopted. The Central Electricity Board has accepted meters as satisfactory provided they are within the specified limits of accuracy.

Messrs. Dransfield and Hart object to the Class B potential transformers, but I would remind them that as these operate within narrow limits it is easy to apply a suitable correction to the meter for comparatively large potential-transformer errors. In reply to Mr. Eccles, the temperature-error curves in Fig. 1 were obtained from a Type A polyphase meter. Mr. Atkinson is of opinion that the temperature range may be greater than that given, but I have stated that in such cases artificial regulation would be resorted to. Messrs. Nield and Atkinson ask under what conditions it is possible to obtain reversed phase rotation after correct connections have been made. So far as I know there are none, but I am aware of several cases where reactive-kVAh meters have been connected in this way initially and the error has not been discovered for many months. These cases, it may be stated, were not connected with grid metering. The wave-form shown in Fig. A by Mr. Howarth is scarcely likely to appear in connection with grid metering, owing to the widespread use of delta-connected transformers. While there are several possible remedies, their application would depend on the commercial error introduced, as distinct from the reactive kVAh metering error; and while the latter may be relatively large, the former may be quite small. The case illustrated in Fig. B could be more simply met by a 2-element impulsing summator receiving impulses from two interlaced series coil meters. This arrangement would overcome all voltage difficulties and would be capable of easy extension. With regard to the case of G1 metering having been installed in a G2 station, it is impossible to give a reason for this without a knowledge of local conditions. The term "Var" suggested by Mr. Bridge is already in use, and many of the reactive-kVA indicating instruments installed by the Central Electricity Board have the words "Kilo-Vars" and "MegaVars" printed under the scales. Tradition dies hard, but it is likely that the term will yet come into general use. In reply to Mr. Bishop, the estimated losses in the Scottish area agree with the metering results to within about 9 per cent.

It was to be expected that some interest would be shown in the question of diamonds versus sapphires, and this is raised by Messrs. Howarth, Dransfield, Mears, and Lawson. I have no doubt, even after only a few years' experience with sapphires, that diamond jewels will prove easier to maintain, but it seems probable that sapphires, while requiring to be changed more often, will prove less expensive in the end. A careful record is being made in Central Scotland of the average life of sapphire jewels, but it will be some time yet before any definite opinion can be given. The oil used with the sapphires is a highly refined mineral oil with a viscosity of 350–400 at 20° C. and a flash-point of 190° C. I agree with Mr. Lawson that, in view of the magnetic suspension of the Type B meter, "support" would have been a better description. The magnetic suspension device is not new: it was in use and giving satisfaction before the inception of grid metering. I cannot agree that reducing the weight of the rotor will not improve jewel wear. It seems obvious that, other things being equal, the lower the pressure on the jewel the less the effect on the bearing.

The question of testing and test points is raised by

Mr. Buckley, and I am glad to note that he agrees with the proposal to carry out check tests on site by means of a portable rotating sub-standard. It is possible, on the test points provided, to disconnect the meter entirely from the current transformers and connect the sub-standard in series on a phantom load. This reduces the testing to mere routine. I regret that Mr. Gibbons does not agree with the proposal to test on site. I think he will find that, apart from the noise of running machinery, there is little to distract the attention of the testing engineer in most positions in which grid meters are installed.

Mr. Burton apparently considers that testing on site by means of a rotating sub-standard does not go far enough and is insufficient to give a satisfactory test on grid meters. The instances of faults which he gives, however, are almost entirely taken care of by the methods adopted on the Central Electricity Board installations. Special test points are provided for insertion of the portable sub-standards, so that it is unlikely that any other part of the wiring will be disturbed. Indicating lamps are provided to show when potential fuses blow, and in a very large number of cases the main and check meters are provided with separate current transformers. In view of the fact that it is almost impossible for a skilled engineer to open-circuit the secondaries of the current transformers, a breakdown between turns is a very remote possibility, so that the provision of a separate test winding on all current transformers is considered unnecessary.

Regarding the question asked by Mr. Gray in connection with the accuracy with which Type B reactive-kVAh meters can be tested, as the sub-standard is provided with its own auto-transformer there is no question of overloading the transformer on site. Mr. Page commends the practice of recording on the test certificates the meter accuracy with and without current transformers, and I have to confirm that this is done in all cases connected with the grid. Mr. Green is doubtful of meters calibrated apart from their current transformers, but I am glad to note that this practice is commended by Mr. Lawson. In reply to Mr. Morris, the sub-standard meters would normally be checked before and after each test on site, entailing standardization not more often than once each month. Prof. Parker Smith's reference to the standardization arrangements in Scotland is a timely one, and I feel that supply authorities would do well to support the testing institutions and colleges in this respect, instead of duplicating expensive apparatus for the same purpose.

Transmission of Impulses.

The ideal method of transmitting impulses is referred to by Messrs. Page and Mears, but the method suggested by them will require considerable development before it can be applied successfully to summation metering. Messrs. Holmes, Clarke, Gray, Page, and Knight, all raise the point about the effect of the meter contactor on the meter at light loads. Messrs. Holmes and Page do not admit that the cam-operated contactor has any appreciable effect, while Mr. Clarke states that his records show a tendency to slow down the Type B meter at light loads. Mr. Knight admits the effect and asks how the main meter is compensated for this in comparison with the check meter. Both meters are fitted with contactors, so that the effect is the same in both cases. Mr. Gray points out that all the cam-contactor meters have a higher torque, but he omits to mention the higher full-load speed of the Type A meter. I do not think there is much to choose between the methods, provided proper precautions are taken, and this has been done by all the manufacturers. The commutator has the advantage of a perfect wiping action, as mentioned by Mr. Cheetham, and I should like to reassure Mr. Webb as to its life when compared with that of the cam-type contactors. The commutator shows up badly when an electrical fault occurs on the transmitting circuit, as in this case it is usually so badly damaged as to necessitate replacement, but for normal operation it will give service equal to any of the cam contactors. Mr. Page states that a desirable feature in a meter contactor is that the contacts should not linger. This is not necessarily so as such a point can be, and is, taken care of in the receiving mechanism. In the Type C meter, however, owing to the design of the receiver this point is essential and is effected successfully by the gravity-operated device. Mr. Gray expresses doubt on the point, but reference to Fig. 5 will clear up any uncertainty in this connection. Mr. Gray also refers to the possible transmission of impulses owing to vibration of the cam-contactor springs. Such trouble has occurred, but has been successfully overcome by suitable design.

The vexed question of graded impulsing is raised by Messrs. Holmes, Nield, Gray, and Atkinson. There can be no doubt that for uniform accuracy throughout the equipment, graded impulsing is essential. The example given in the paper shows this clearly, and I can assure Messrs. Holmes and Nield that there are cases where it is possible to obtain considerably greater errors if a high impulsing speed is not employed. I refer Mr. Eccles to Fig. 9 for an explanation of how negative impulses are traded against positive with graded impulsing. It will be clear that this device functions independently of the relative size of positive and negative impulses.

Messrs. Cheetham, Nield, and Hart, refer to the life of the contacts. Mr. Cheetham states that the life assumed in the paper of 10^7 impulses has been exceeded. This is quite true, but in dealing with grid metering generally I still adhere to the opinion that this figure is a reasonable minimum. I feel sure that many of the contacts will have a life of 5×10^7 impulses: much will depend on the duty. If Mr. Nield had to maintain a large summation equipment I feel sure he would replace all contacts within a very short time if a reasonable number showed signs of wear, so that it is probably better that they should wear out together. In reply to Mr. Hart, there are other parts which may give trouble besides the contact surfaces, but occasional cleaning will maintain good contact and prevent errors in impulsing. His experience with regard to telephone equipment appears to be unusual, but I am quite certain that the contacts provided for telephone work would not stand up to the requirements of summation metering as at present designed. The contacts employed on the grid metering equipments referred to by Mr. Hill are made either of pure silver or of a silver alloy containing over 90 per cent silver.

In reply to Mr. Mears, the comparison of the meter and summator repeater dials has in general been excellent. In a few cases the repeater dials have been found in advance, particularly on the Type A equipment, but it is more usual for impulses to be lost than gained.

The question of the relative merits of a.c. and d.c. supply for impulse transmission is raised by Mr. Rawll. I have no preference in the matter, provided satisfactory arrangements are made to ensure that the supply is maintained. In most cases an indicating lamp is provided to show that the d.c. supply is through to the equipment, and where alternating current is employed selector relays are provided to make certain that an a.c. supply is always available. Should the whole supply fail, of course, no impulsing can take place, nor is it necessary.

Demand Indicators and Summators.

Mr. Gibbons asks why two demand indicators have not been provided, but his remarks show that it is a duplicate summation equipment which he requires. The equipment provided by the Central Electricity Board is giving such good service and is self-checking to such an extent that a duplicate equipment is unnecessary. At the same time Mr. Gibbons condemns the summation equipment installed to measure reactive-kVA demand and power factor, but no suggestion is made of a suitable alternative. Mr. Clarke raises the question of the difference between the maximum demand indicator and printometer readings. It is gratifying to note that any difference which has been observed is well within the prescribed limits on the Type B equipment, and this can also be confirmed for the other printer equipment.

In reply to Mr. Howarth, if the same maximum demand occurred twice in one month the lower power factor would be taken in all cases. This must follow from the fact that where power factor enters into any tariff it is intended to penalize low power factor. Mr. Howarth must be already aware that the power-factor penalty is passed on by many supply authorities to their large consumers in the form of a kVA charge. I am quite sure that this is effective in providing protection against any power-factor penalty in the 1926 Act or any tariff which may be framed by the Central Electricity Board. As this was the practice on many supply systems before 1926, it cannot be said that the operations of the Central Electricity Board are subjecting the supply authorities to any hardship.

Mr. Clark has raised a most important point in connection with the adjustment of accounts according to the power factor of the supply. Unfortunately the question is not entirely dependent on the tariffs introduced by the Central Electricity Board. The method of adjustment for power factor has been defined by the Electricity Commissioners under the Electricity Supply Act of 1926. The most satisfactory tariff to fulfil the conditions outlined by Mr. Clark is one based on maximum kVA, and this method is favoured by many supply companies in penalizing their consumers for low power factor. It seems anomalous that a consumer can actually lower his total charge by consuming more energy.

Printometers.

Mr. Page upholds the maxigraph and states that it is quite suitable for accountancy purposes. I still do not agree. Perhaps it should be explained that the accuracy of 1 part in 1 000 given in the paper is that claimed by the manufacturers; it would not be admitted by any of the Central Electricity Board's staff who have to handle the maxigraph charts. The accuracy in practice is certainly not greater than 1 in 300, or about 0·3 per cent of full scale. Mr. Gibbons confirms the difficulty of utilizing the charts for accountancy purposes, and when the maximum demand approximates to half-scale or less the objection is fully justified. In reply to Mr. Mears and Mr. Petch, the resetting time varies from 2 to 10 seconds in the various types of summators. Correction is applied either by storage of lost impulses or by modification of the gear ratios involved. After the criticism of the statement in the paper regarding the life of the type wheels by Messrs. Gibbons, Nield, Ritter, and Hart, I may be allowed to modify my opinion. The examples given in the discussion show what modern type-wheels will stand.

Mr. Holmes uses a *reductio ad absurdum* argument to prove that a vernier is unnecessary on the printometer type-wheels. His argument is quite sound for a separate printer such as that used with the Type B and Type D equipments, but it does not hold good for the case of an incorporated printer and graded impulsing such as we have on the Type A summator. In this case either a fifth wheel or a vernier on the fourth is an essential feature, and greater accuracy is obtainable not because of the vernier but because of the graded impulsing. The high speed of impulsing between the summator and the printer referred to by Mr. Clarke and explained by Mr. Gray is particularly noticeable on the Type B equipments. The high impulsing speed is necessary for greater accuracy.

Maintenance.

Mr. Nield refers to the importance of accessibility from the point of view of maintenance, but I do not think there is much to choose between the various equipments in this respect. The Type B equipment appears to be better than the others, but it is not so in practice. Visibility should not always be accepted as proof of accessibility. I agree with Mr. Atkinson that the satisfactory service given by the grid equipments is due to efficient maintenance work, but I cannot accept Mr. Lawson's statement that the maintenance programme proves that a great deal of trouble has been experienced. Mr. Buckley's contribution to the discussion shows that he has an elaborate maintenance system, but I do not think this could be claimed as proof of serious difficulty with his metering installations. It is too early yet to give Mr. Morris any comparison of maintenance costs. To obtain a fair comparison, costs must be averaged over a number of years.

Mr. Fawssett makes unfavourable comparison of the grid metering equipments with averaging recorders in respect of faults. Mr. Gibbons in his contribution to the discussion states that the older types of averaging recorders have given considerable trouble, so that Mr. Fawssett's comparison is rather unfair. He is comparing a recorder which has apparently been fully developed, with equipment which has scarcely passed the development stages. The figures given in the paper are regarded as satisfactory for the present equipments, but there is no doubt that with further development better results will be obtained.

General.

Mr. Fawssett expresses a preference for electrical summation; after experience with both methods I am of the opinion that the Central Electricity Board decided wisely in the adoption of impulse summation. Electrical summation appears simpler, but it is more inflexible and incapable of easy extension. The errors in the case of impulse summation can be predetermined without difficulty, and further developments will favour the impulse method. Mr. Mears puts forward an interesting suggestion, but it is similar in many respects to the Type C equipment. I am afraid that chemical methods, as suggested by Mr. Sandeman, are quite impossible. Mr. Page complains that a host of details have been omitted from the paper, but most of the points he mentions are regarded as self-evident. With regard to Fig. 2, the details for which he asks are given below the diagram. The word "absorbed" instead of "delivered" would give an entirely wrong meaning, as it is the kWh delivered to the station busbars to which reference is made. Similarly, the words "owing to high meter loading" as used in the paper are correct. I must refer Mr. Page to the definition of "any consecutive 30 minutes" as given in the paper. This was laid down by the Electricity Commissioners, and the metering equipments adopted by the Board are designed to meet the requirement. Mr. Ritter asks whether it is not possible to jack-in meter circuits. Even if the apparatus justified it on the grounds of simplicity, such a practice would not be countenanced by responsible meter engineers owing to the possibility of introducing resistance in series with the current circuits. Unless mercury switches were used a similar difficulty would arise in regard to the suggestion to switch out idle circuits in electrical summation, made by Mr. Caton. I think difficulty would also be found in obtaining a suitable relay.

The question of clocks and timekeeping is raised by Messrs. Page, Ritter, and Eccles. I agree that information regarding the design and operation of the clocks in use would have been of considerable value, but as there is sufficient material for a separate paper on the subject it was better to omit all reference to clocks rather than include incomplete information in the present paper. The majority of the clocks are not synchronous but are battery-operated, so that they are unaffected by discontinuity of supply. The cumulative error which may occur, as suggested by Mr. Eccles, is prevented by regular checking from the master control clock. This check is not automatic; it is carried out by telephone. Cases are on record where the clock, after regulation, has only varied a few seconds over a year's run. Dr. Garrard suggests a central metering equipment. This has already been considered, not so much for accountancy purposes as for control of generation, and approximate methods are already in use for obtaining instantaneous demand readings. I do not think that it will ever be found necessary to transmit unit readings to a central point.

Messrs. Turner and Hart suggest that meter manufacturers and telephone manufacturers might have co-operated in the production of a satisfactory summation equipment. I have always been surprised that so much time and money should have been spent in developing four different systems when by co-operation one standard method could have been adopted. Apart from this, however, the meter manufacturers are to be congratulated on having solved the problem by four separate methods.

SOME MEASUREMENTS OF THE ELECTRICAL CONSTANTS OF THE GROUND AT SHORT WAVELENGTHS BY THE WAVE-TILT METHOD.[*]

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[From the National Physical Laboratory.]

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Summary.

The paper gives an account of some measurements of ground electrical constants κ and σ made by the tilting-rod apparatus, being a continuation, on shorter waves, of the experiments described in an earlier paper. The employment of higher frequencies involved some modification of the apparatus and also an extension of the theory to allow for the effect of the dielectric constant, which begins to influence the results under these circumstances. The paper divides the measurements into four groups: (1) Measurements made at one site over prolonged periods to investigate seasonal variation. (2) Measurements on selected sites over a large range of wavelengths to determine κ and σ. (3) Summary of all measurements made at a number of different sites to determine σ only. (4) Measurements made on sites with abnormal ground surface, singled out in a separate table for the purpose of emphasis and comment.

A theoretical section is devoted to the extension of the analysis of the field of a plane wave advancing over the surface of an imperfect conductor, in order to derive a simple relationship between wavelength, tilt angle, conductivity, and dielectric constant. Values of σ and κ are obtained by plotting a suitable function of tilt angle against frequency and choosing from a series of theoretical curves, plotted for different values of σ and κ, that which most nearly fits the results. It is concluded that no seasonal change of σ was detectable, but that changes from wet to dry weather had an appreciable effect and that the conductivity was not appreciably different from its long-wave value. The series of measurements taken on a large area of ice over deep fresh water probably constitute the most interesting results, giving values of 100 for κ and $1 \cdot 4 \times 10^8$ for σ. Theory indicates that the results may be regarded as applying to the water rather than to the ice. This is confirmed by the value of κ obtained, which corresponds approximately to the normal "static" value of the dielectric constant of water and is many times greater than that of ice.

Introduction.

The experimental work which forms the foundation of this report consisted in making measurements of the forward tilt of ground waves by means of a rotating "Hertzian rod" apparatus. A description of an instrument of this type and its method of use has already been given in an account of a similar investigation on medium and long waves carried out by R. L. Smith-Rose and the present author.[†] The measurements were made on signals from a small-power local transmitter at a sufficient distance away to ensure that plane-wave conditions could be assumed at the receiver.

The measurements were made at some twenty different localities in England and Scotland on wavelengths from 12 to 300 metres, and under widely varying surface and seasonal conditions. Since the tilt angle is a function of the electrical constants of the soil immediately surrounding the receiver, the measurements can be used to gain information about these constants, whereas each measurement constitutes a direct determination of that important function of conductivity, dielectric constant, and frequency (denoted in this paper by the symbol κ'), of which the square root may be defined as the effective refractive index of the ground for the particular wavelength under investigation. The importance of this constant is that it enables the reflection coefficient and surface attenuating properties of the ground to be determined.

Since this investigation was carried out a considerable amount of attention has been paid by other workers to the problem of determining ground constants. Thus Smith-Rose,[†] employing a method of measuring samples of soil in the laboratory over a very large range of frequencies, has found that the values of both the constants vary with frequency and moisture content; while Feldman[‡] has measured them by a rotating-rod method very similar to that described in the present paper, and also by a sample method somewhat similar to that employed by Smith-Rose. Both the above obtain values for conductivity and dielectric constant which, in cases when the experimental circumstances are in common, are of the same order, and vary between limits of the same order, as those obtained in the experiments about to be described.

Description of Apparatus.

The apparatus differs in no fundamental respect from that already referred to (*loc. cit.*), but embodies several improvements and refinements.

The Hertzian dipole (10 ft. long) is made of aluminium tube of $\frac{3}{4}$ in. diameter, and the horizontal axis about which it rotates normally is 7 ft. above the ground. The leads from the dipoles to the primary of the coupling transformer are enclosed in the hollow brass horizontal axis, spaced apart and held equidistant from the walls of the tube by tight stretching. It is found to be essential that these leads shall be absolutely symmetrical as regards their capacitance to the framework of the system. The primary and secondary of the coupling transformer, situated immediately below the horizontal axis, are separated by a concentric electrostatic screen of parallel wires spaced 1 in. apart. The primary rotates with the horizontal axis carrying the dipole, and the secondary remains stationary with respect to the receiving apparatus, to which it is connected by means of down-leads spaced apart inside the vertical tube which projects into the large screening box containing the amplifier.

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[*] The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

[†] *Proceedings of the Royal Society*, A, 1925, vol. 107, p. 587.

[†] *Proceedings of the Royal Society*, A, 1933, vol. 140, p. 359.

[‡] *Proceedings of the Institute of Radio Engineers*, 1933, vol. 21, p. 764.

PROCEDURE.

The vertical axis is first carefully adjusted to be truly vertical by levelling the box; after this the horizontal axis is aligned in a direction perpendicular to the transmitter, which consists of a battery-driven oscillator coupled to a short vertical aerial and is set up at least 100 metres away from the tilt-measuring apparatus.

The measurement consists in swinging the Hertzian rod aerial about a horizontal axis between two angular positions (read off on a scale) on either side of the position of minimum signal strength which give equal intensity of sound in the telephones. The mean of the two angles defining these two positions then gives the angle at which the aerial picks up the least energy. Since the resultant electric field of the ground wave which is being received is elliptical in form, the method just described determines the direction of the minor axis of this ellipse. This therefore gives the tilt angle of the wave, which is defined as the inclination to the vertical of the major axis of the ellipse.

The operation is repeated with the horizontal axis turned through 180° about its vertical supporting axis. To complete what constitutes a single observation the horizontal axis is now turned alternately to each of the two positions in line with the direction of travel of the wave, measurement of what may be called the "sideways" tilt of the wave being made in each case. The purpose of this operation is mainly to verify that the apparatus is in working order. The angle in all cases should closely approach zero. If there is a larger departure, it is an indication either that the apparatus is faulty or that the site is unsuitable. A small constantly-repeated sideways tilt, however, on a site which is beyond suspicion, may be used as an instrumental correction to be added to or subtracted from the forward-tilt measurements according to its sign. Observations are then made in turn on the other wavelengths of the series.

THEORY.

Let X = resultant horizontal electric force at earth's surface along direction of travel of wave,

Z = resultant vertical electric force at earth's surface,

σ = conductivity of ground at surface (e.s.u.),

κ = dielectric constant,

$\kappa' = \kappa - 2j\sigma/f$ = square of effective refractive index for frequency f,

θ = angle of incidence of wave (i.e. angle with normal to surface),

$j = \sqrt{(-1)}$,

ρ_v = reflection coefficient of vertically polarized wave, defined as the ratio (Total field strength of reflected ray)/(Total field strength of incident ray).

It can be shown that the value of the resultant electric component in a vertically polarized wave at the earth's surface, in order to satisfy the fundamental boundary conditions and the elementary laws of reflection and refraction, must be represented by the following:—

$$X = (1 - \rho_v) \cos \theta \, E \tag{1}$$

$$Z = (1 + \rho_v) \sin \theta \, E \tag{2}$$

$$\frac{1 - \rho_v}{1 + \rho_v} = \frac{\sqrt{[1 - (\sin^2 \theta/\kappa')]}}{\sqrt{\kappa'} \,.\, \cos \theta} \tag{3}$$

Hence
$$\frac{X}{Z} = \frac{\sqrt{[1 - (\sin^2 \theta/\kappa')]}}{\sqrt{\kappa'} \,.\, \sin \theta} \tag{4}$$

For the case of a ground wave there is no reflected wave, so that we have $\rho_v = 0$. This gives

$$\begin{aligned} X/Z &= \cot \theta, \text{ from (1) and (2)} \\ &= 1/\sqrt{\kappa'} \text{ from (3)} \end{aligned} \tag{5}$$

a relationship which may be derived from the equation of Sommerfeld and Zenneck and is also given by Bouthillon. Equation (5) shows that the vertical and horizontal components of the electric field are not in phase, since κ' is a complex quantity. That is, it defines the elliptical rotating field which is characteristic of a wave-front advancing over an imperfect conductor.

The direction of the minor axis of this ellipse corresponds to the position of the rotating dipole in its minimum position, and the inclination of the major axis to the vertical is defined as the angle of tilt (ϕ).

It can be shown that on expanding (5) we get

$$\cot \phi - \tan \phi = (\kappa' - 1)/\sqrt{[\tfrac{1}{2}(\kappa + \kappa')]}$$

which for small values of ϕ reduces to

$$\tan^2 \phi = \frac{\kappa + \sqrt{[\kappa^2 + (2\sigma/f)^2]}}{2[\kappa^2 + (2\sigma/f)^2]} \tag{6}$$

A series of graphs of this function of the tilt with respect to frequency are shown in Fig. 2 for various values of σ and κ. It will be seen that for small values of f they approximate to the straight line

$$\tan^2 \phi = c/(4\sigma\lambda) = f/(4\sigma) \tag{7}$$

(this is the expression used for the determination of σ in the previous paper[*]) and to the horizontal straight line

$$\tan^2 \phi = 1/\kappa \tag{8}$$

for large values of f.

Tests were also made to ascertain the minimum distance by which the transmitter had to be separated from the receiver to ensure that the ground waves had established themselves in the required manner. It was found that a distance of 100 metres was safe on all wavelengths employed.

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[*] *Proceedings of the Royal Society*, A, 1925, vol. 107, p. 587.

MEASUREMENTS.

(i) *Seasonal Measurements at Ditton Park* ($\lambda = 24$ *metres*).

A series of measurements extending over some 13 months were made at Ditton Park, Slough, on a fixed wavelength of 24 metres. They were made at the same spot in an open space at the centre of a large field. At the beginning of the series the measurements were made once per week, but as time and service were not available throughout the whole period the later observations were subject to considerable interruption.

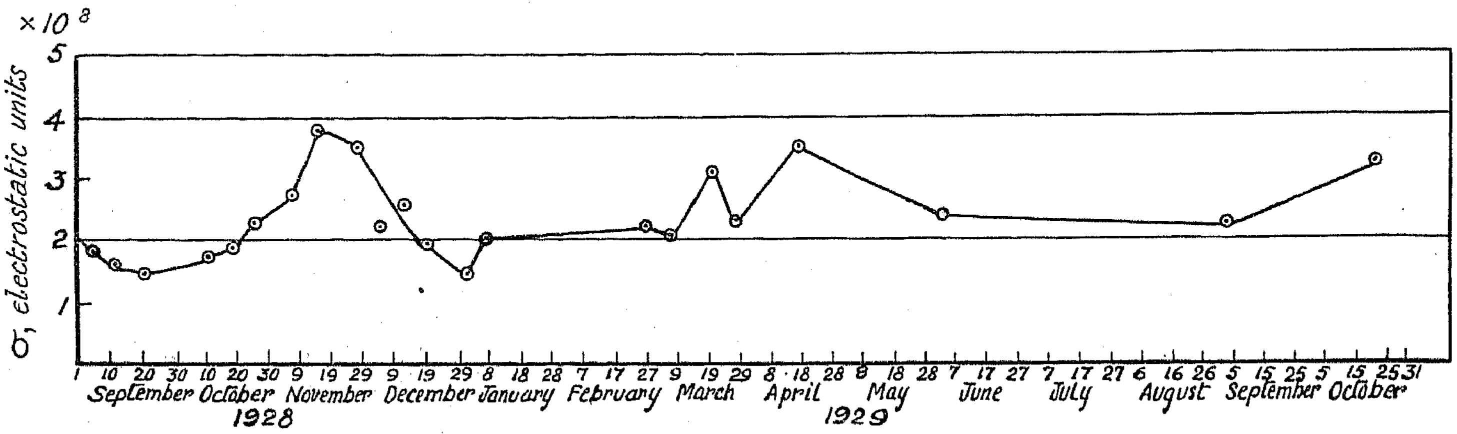

FIG. 1.—Summary of tilt measurements taken at Ditton Park.

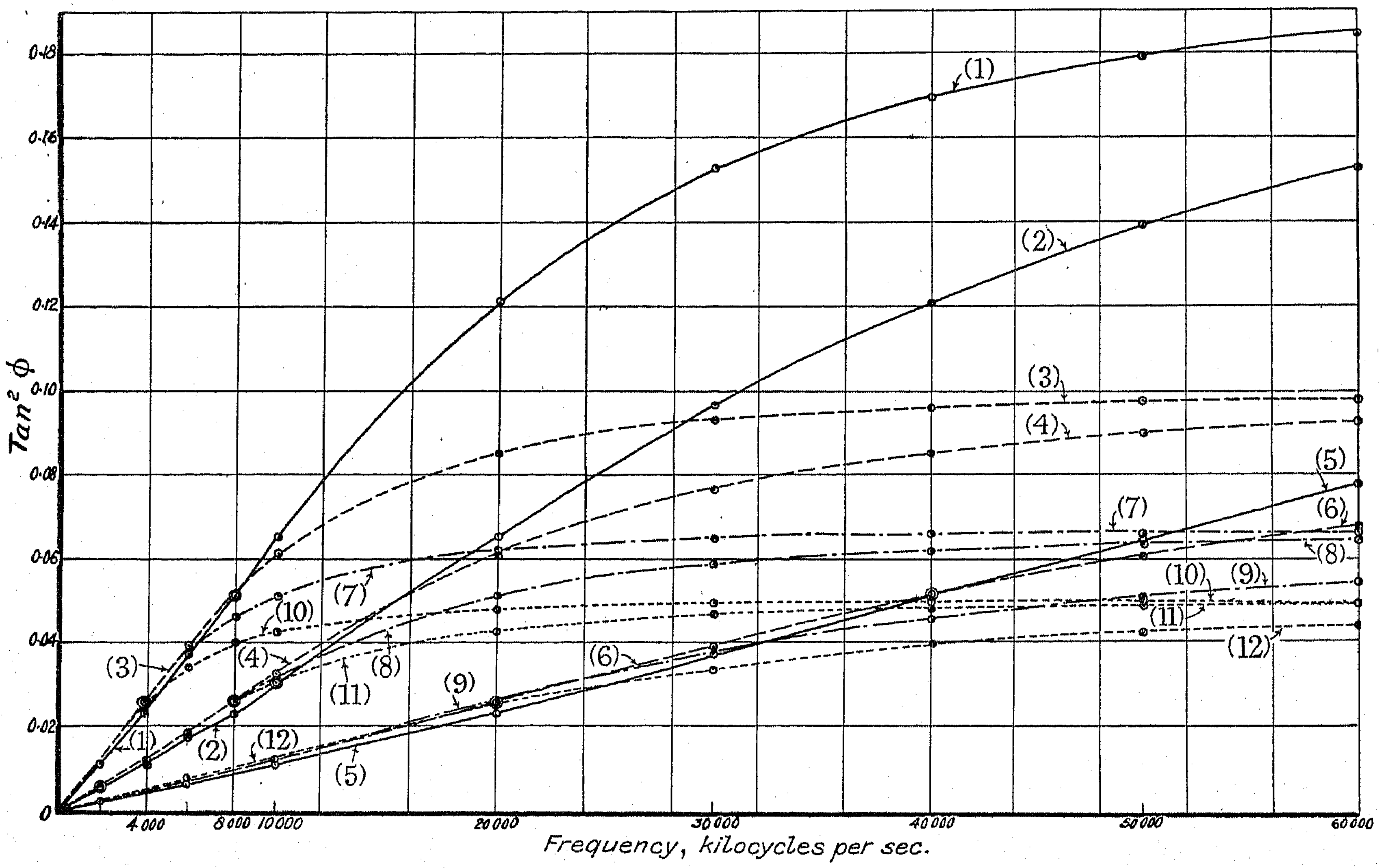

FIG. 2.

(1) $\sigma = 0{\cdot}5 \times 10^8$, $\kappa = 5$; (2) $\sigma = 1{\cdot}0 \times 10^8$, $\kappa = 5$; (3) $\sigma = 0{\cdot}5 \times 10^8$, $\kappa = 10$; (4) $\sigma = 1{\cdot}0 \times 10^8$, $\kappa = 10$;
(5) $\sigma = 2{\cdot}5 \times 10^8$, $\kappa = 5$; (6) $\sigma = 2{\cdot}5 \times 10^8$, $\kappa = 10$; (7) $\sigma = 0{\cdot}5 \times 10^8$, $\kappa = 15$; (8) $\sigma = 1{\cdot}0 \times 10^8$, $\kappa = 15$;
(9) $\sigma = 2{\cdot}5 \times 10^8$, $\kappa = 15$; (10) $\sigma = 0{\cdot}5 \times 10^8$, $\kappa = 20$; (11) $\sigma = 1{\cdot}0 \times 10^8$, $\kappa = 20$; (12) $\sigma = 2{\cdot}5 \times 10^8$, $\kappa = 20$.

$$\tan^2 \phi = \frac{\kappa + \sqrt{[\kappa^2 + (2\sigma/f)^2]}}{2[\kappa^2 + (2\sigma/f)^2]}$$

The results are shown in Fig. 1 in the form of a curve connecting the date of observation with the conductivity as derived from the tilt angle by the method described above. The meaning of the true conductivity as applied to a medium in which this quantity naturally varies with depth, and the justification for ignoring the dielectric constant, are discussed later.

It will be observed that the value σ lies between $1{\cdot}5 \times 10^8$ and $3{\cdot}6 \times 10^8$ electrostatic units throughout the whole year, which included spells of all kinds of weather, among them being severe frost and snow, hot and dry spells, and periods when flood conditions prevailed.

There appear to be some signs of a slow drift of the value of σ above and below its mean value. This was clearly not a true seasonal variation, but more probably related to wet and dry spells. In fact, the minimum and maximum values occurring in October and November, 1928, did correspond to the middle of dry and wet spells respectively. The results show that variation of the order of 2 : 1 may occur as a result, presumably, of changes in the surface due to weather conditions.

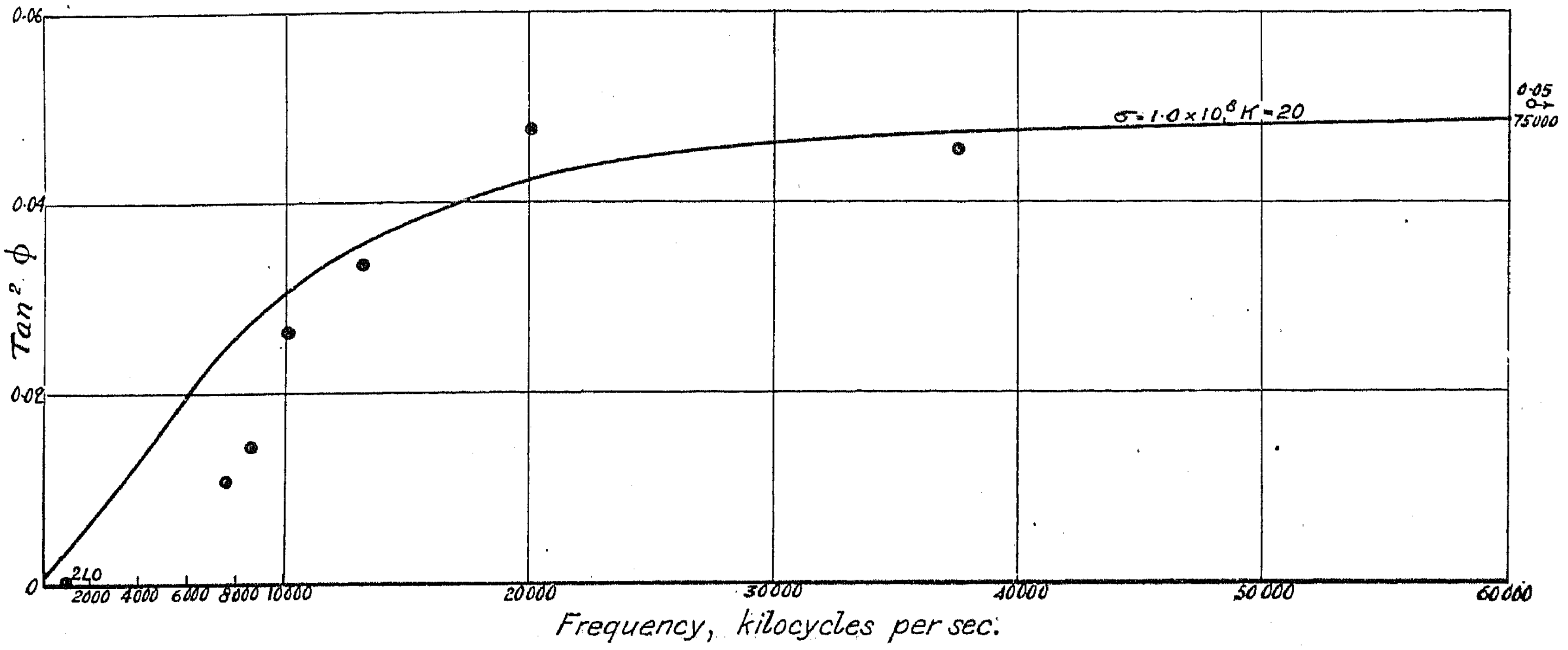

Fig. 3.—Tilt measurements on Stoke Common, 21st November, 1929. (Soil very wet.)

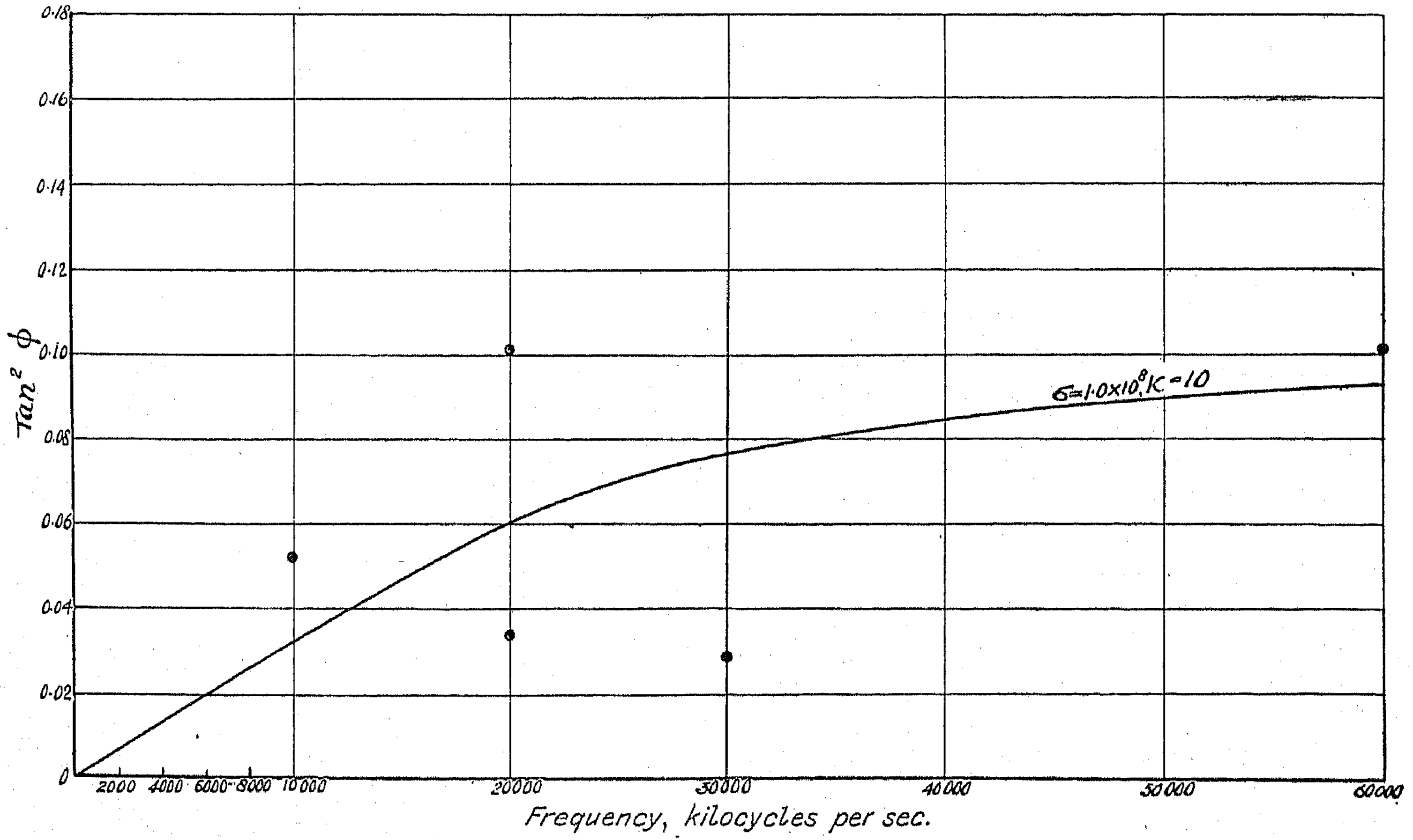

Fig. 4.—Tilt measurements on Dorney Common, 22nd October, 1929. (Soil very dry.)

(ii) *Measurements on Several Wavelengths to Check Theory and Determine κ and σ.*

These were carried out on several sites, and included measurements on ice over deep fresh water on a large reservoir at Staines.

By plotting the experimental results in the form of the graphs similar to those shown in Fig. 2, i.e. values of $\tan^2 \phi$ against frequency, it is possible to find a theoretical curve corresponding to a definite value of σ and κ which fits the experimental values. This has been done in Figs. 3, 4, 5, and 6, for the measurements made at Stoke Common, Dorney Common, Crookham Common, and Staines Reservoir (ice). Table 1 shows the values of σ and κ obtained in this way for the various cases.

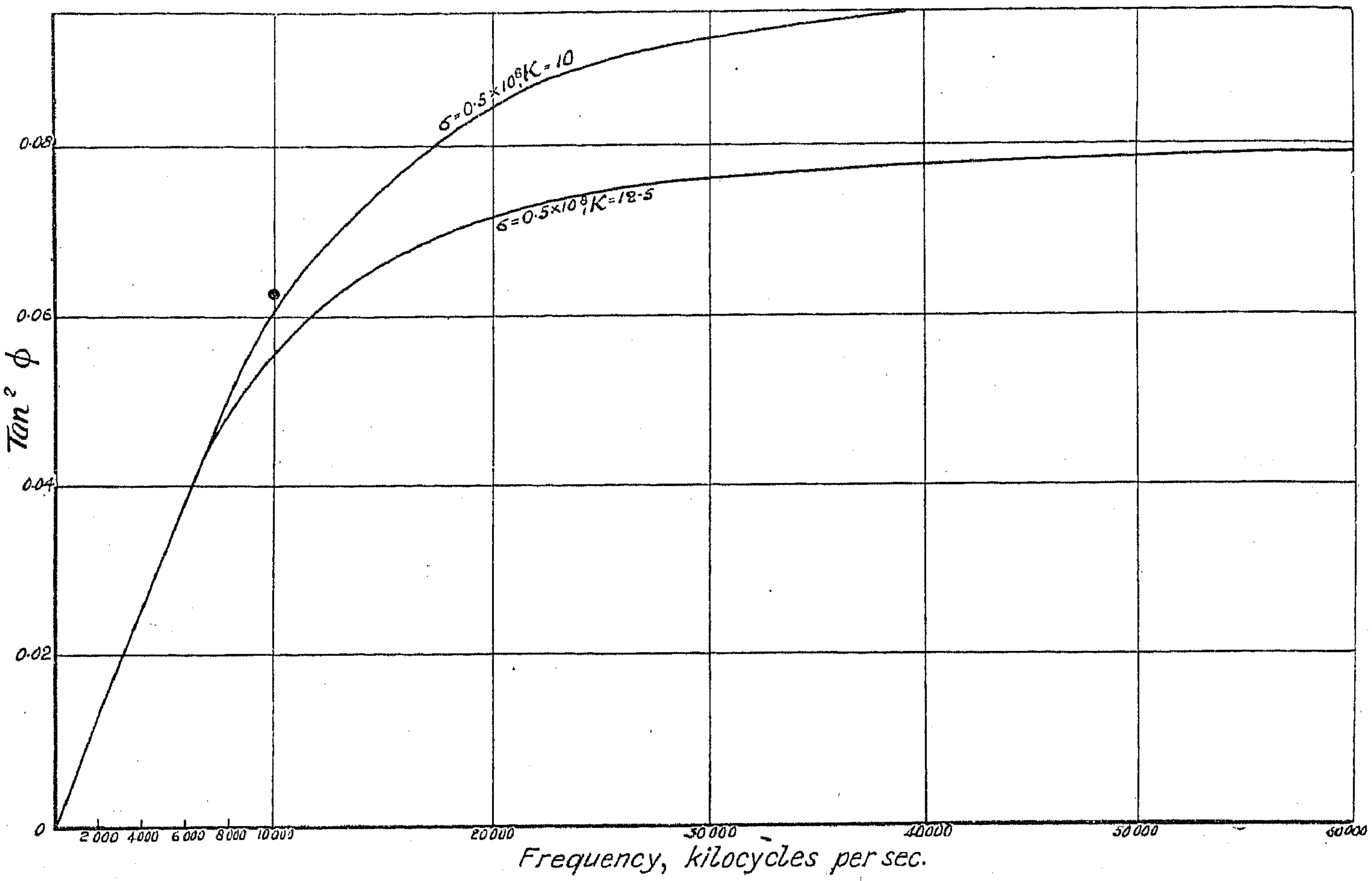

FIG. 5.—Tilt measurements on Crookham Common, 23rd October, 1928.

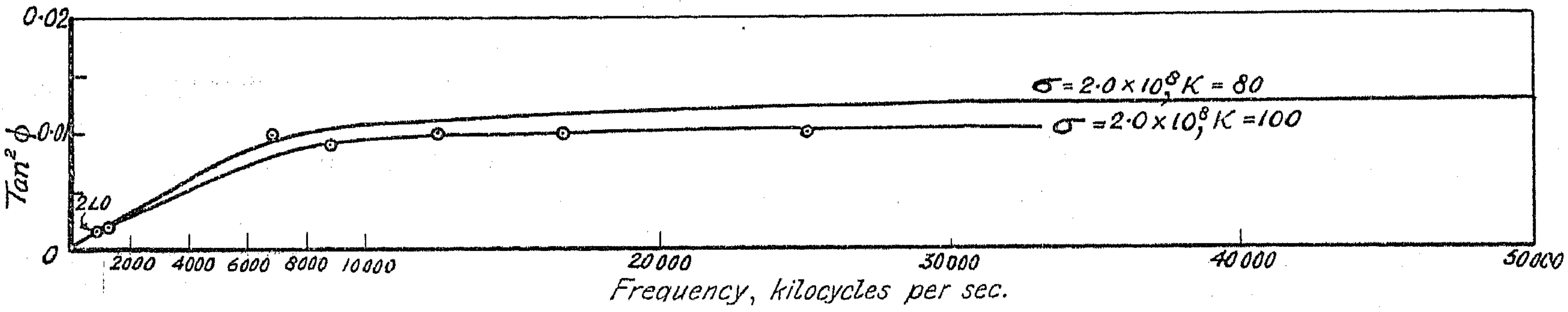

FIG. 6.—Tilt measurements on ice at Staines Reservoir, 1st March, 1929.

TABLE 1.

Locality	Condition			Remarks
		e.s.u.		
Ditton Park, Bucks ..	Dry soil	$2 \cdot 3 \times 10^8$	< 30	Apparently some disturbing effect
Stoke Common, Bucks	Very wet	1·0	20	
Dorney Common, Bucks	Water meadow	1·0	10	
Crookham Common, Berks	Barren and stony common	0·5	10–12·5	Only three observations
Staines Reservoir ..	Ice on fresh water	2·0	100	
Marlborough Downs, Wilts	Chalk down	1·3	< 30	

(iii) *Measurements of σ at Miscellaneous Sites.*

These measurements were made at various sites, mainly for the purpose of determining σ on the assumption that κ can be neglected. The curves of theoretical values given in Fig. 2 show that to a first approximation if $\kappa < 20$ this holds good where $\sigma > 1 \cdot 0 \times 10^8$ and $\lambda > 20$ metres, and where $\sigma > 2 \cdot 0 \times 10^8$ if $\lambda > 10$ metres.

In Table 2, which gives the results of these measurements, the measurements contributing to Table 1 are also included for the sake of obtaining a comprehensive list

(iv) *Measurements under Abnormal Surface Conditions.*

Table 3 shows the values of σ and of κ (where possible) obtained under abnormal conditions.

These results, which have also been included in Table 2, are set out by themselves in order that these particularly interesting conditions may be studied separately. They show that a thin covering of ice and snow does not affect materially the constants of the ground or water beneath.

TABLE 2.

Date	Place	Surface	Subsoil	λ	σ
				metres	e.s.u.
29 Jan., 1932	Baldock, Herts	Loam	Chalk	16–35	$1 \cdot 5 \times 10^8$
	Chipping Norton	Grass field	Limestone	17	5·0
	Crookham, Berks	Sandy common		17–44	0·5
29 Feb., 1932	Dairsie, Fife			16–35	1·3
	Ditton Park, Bucks	Grass field	Gravel	17	1·8
29 Oct., 1932	Dorney Common	Water meadow	Clay	7–356	1·0 to 2·2*
	Enstone, Oxon		Limestone	17	1·2
	Farnborough, Hants	Grass field	Gravel	43	2·16
28 Aug., 1932	Leafield, Oxon	Grass field	Limestone	15–17	3·7
28 Aug., 1932	North Mimms, Herts	Grass field	Gravel	17–30	1·3
29 Oct., 1932	Marlborough Downs, Wilts	Downland grass	Chalk	15–45	1·5
29 Feb., 1933	Rugby	Grass field		16–35	4·1
	Strathkinnes, Fife	4 in. snow		16–35	1·1
	Stoke Common, Bucks	Peaty common	Clay and gravel	7–356	1·7
	Terling, Essex	Grass field		24	1·5
29 Mar., 1933	Staines Reservoir	4 in. ice	Fresh water 30 ft. deep	11–356	1·4

* Soil very dry.

The most interesting of these abnormal cases is probably that of the measurement on the ice at Staines Reservoir. This is a piece of open water some 400 acres in extent and about 30 ft. deep. It is cut in two by a narrow partition carrying a footpath. The water which it contains is pumped direct from the neighbouring River Thames, and may remain in the reservoir a considerable time before it is passed on to the purifying plant. It therefore consists of unpurified river water which may have stood for several months.

TABLE 3.

Locality	σ	κ	Conditions
	e.s.u.		
Staines Reservoir	$1 \cdot 4 \times 10^8$	100	Ice 4 in. thick on fresh water 30 ft. deep
Dairsie	1·3	—	Ground covered with snow 4 in. deep
Strathkinnes	1·8	—	Ground covered with snow 4 in. deep
Ditton Park	4·5	—	Ice 4 in. thick on fresh water 2 ft. deep
Crookham Common	0·5	12	Very dry peaty common over sand and gravel

The experiments were carried out at distances of 500 and 200 ft. respectively from the nearest banks. There is little doubt that the values of σ and κ obtained apply to the underlying water and not to the ice surface. Firstly, on theoretical grounds it may be shown that the relatively thin layer of ice having a low effective refractive index would have very little influence on the wave compared with the considerable thickness of water immediately below with its comparatively high refractive index; and secondly, on experimental grounds the high values of σ and κ obtained indicate clearly that the effect of the water is predominant.

The fact that the value of 100 was obtained for κ, and not 80, which is the generally accepted value of the dielectric constant for water, is probably an instrumental error. It is possibly due to the greater capacitance to earth of the lower half of the dipole when tilted. The 20 per cent discrepancy thus disclosed is therefore an indication of the limits of accuracy of the whole method. In the case of the measurements made on a shallow ice-covered pond at Ditton Park, on the other hand, both ice and water are probably having little effect and the values of the constants obtained will be due chiefly to the ground beneath. This also applies to the results obtained on the snow-covered ground at Cupar and Strathkinnes.

The measurements at Crookham Common are chiefly of interest as relating to a site of abnormally low conductivity for England. This has enabled the dielectric constant to be determined without employing waves of less than 10 metres length.

CONCLUSIONS.

The conclusions to be drawn from the work described above may be enumerated as follows:—

(1) There is no pronounced seasonal variation of the effective conductivity of the ground under the conditions described. It is difficult, however, to extend this conclusion by generalizing with respect to other localities where changes in surface moisture from winter to summer might be more marked, but it may, at all events, be taken as applying to low-lying cultivated ground in England.

(2) The effective dielectric constant of the ground in typical sites in Southern England lies between 10 and 30 for wavelengths above 7 metres. The experimental points are, however, too scattered to be capable of indicating any departure from the theoretical assumptions, such as a change of the constants with frequency of the type found by Smith-Rose.

(3) The effective conductivities of typical sites in Southern England on waves between 15 and 50 metres vary between $0 \cdot 5 \times 10^8$ and 4×10^8 electrostatic units. The variations from site to site are thus considerable. The values and the magnitude of the variations are of the same order as found for longer waves by the same method in earlier experiments.

(4) The dielectric constant of fresh water (reservoir filled from river) is found to be 100, but it is possible that an instrumental error may account for the discrepancy between this and the value of 80 for the dielectric constant for water, obtained by numerous workers in laboratory measurements at various frequencies up to 200 million cycles per sec.

(5) The experiments show, as theory had already predicted, that where there is a layer of low conductivity or low refractive index on top of a medium for which these constants are high, the lower layer will have a dominating influence in determining the effective constants of the ground.

ACKNOWLEDGMENTS.

The author wishes to acknowledge with thanks the assistance of Mr. G. H. Munro in a large part of the experimental work, and also that of Mr. J. S. McPetrie both in constructing and in making measurements with the special apparatus employed when working on wavelengths below 10 metres.

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ELECTRICAL MEASUREMENTS ON SOIL WITH ALTERNATING CURRENTS.*

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[From the National Physical Laboratory.]

(*Paper first received* 14*th September, and in final form* 11*th December*, 1933.)

SUMMARY.

The electrical properties of the earth play an important part in many modern applications of physics and electrical engineering. In the early portion of this paper a summary is given of the published information on the electrical properties of soil for alternating currents at frequencies from 50 to nearly 200 million cycles per sec. Particular interest is attached to the properties at radio frequencies, and it is shown that, while a certain amount of knowledge has been acquired by the use of field methods depending upon some characteristic of electric wave propagation, the results available apply to certain rather scattered ranges of frequencies and to some fairly localized portions of the earth's surface.

The later portions of the paper are concerned with the investigation of the conductivity and dielectric constant of samples of soil by a laboratory method of measuring resistance and reactance at radio frequencies. This method was used for the majority of the measurements which were carried out at frequencies between 100 and 10 000 kilocycles per sec., but, by the aid of a standard type of capacitance bridge, the work was extended through the audio-frequency range to a power frequency of 50 cycles per sec.

A series of preliminary measurements showed that reliable results could be obtained which were independent of the size and shape of the fixed condenser, in which the soil was packed as the dielectric. The conductivity and dielectric constant were both found to be very dependent upon the moisture content of the soil, except when this was within the normal range for the site under consideration. In a typical case the conductivity for dry soil, at a frequency of 1 200 kilocycles per sec., was of the order of 10^5 electrostatic units (corresponding to a resistivity of 9 megohms per cm cube), while at a moisture content of between 12 and 26 per cent a limiting value of between 10^8 and 2×10^8 electrostatic units (resistivity 9 000 to 4 500 ohms per cm cube) was obtained. The corresponding values of dielectric constant ranged from 3 or 4 for dry soil up to 30 or 40 for very moist soil. The effect of frequency on conductivity was more marked for dry than for moist soil, and in the latter case there was a small although definite rise in the conductivity at the highest frequencies. The dielectric constant decreased with increase of frequency towards a limiting value for moist soil, whereas for dry soil the variation of dielectric constant with frequency was very small. From measurements made on samples of different types of soil it was found that the temperature coefficient of the conductivity at 20° C. was about 2·3 per cent per deg. C., whereas the effect of temperature on the dielectric constant was negligible. In both cases, however, a sudden decrease in the value took place in passing through 0° C., which is attributable to the partial or total freezing of the water content.

When the validity of the laboratory method had been established, and it had been found that the results obtained thereby agreed with those previously available from field measurements, the investigation was extended to a study of the properties of soil from 12 different sites in England and Scotland. In the majority of these cases, samples of soil were obtained for measurement at various depths down to 10 ft., while in one case the depth was extended to 300 ft. The results are given in detail in tabular form in the paper. It is shown that, at a typical frequency of 1 200 kilocycles per sec., the conductivity of surface soil varies between $0{\cdot}16 \times 10^8$ and $4{\cdot}0 \times 10^8$ electrostatic units for different sites, while at various depths the values range from $1{\cdot}6 \times 10^5$ to about 10^{10} electrostatic units. In general it is shown that the clay soils have a high conductivity (i.e. above 10^8 electrostatic units) accompanied by high dielectric constant, and the loam and chalk soils an average value of about 10^8 electrostatic units for conductivity and 20 for dielectric constant, while soil of a sandy or gritty nature gives a much lower conductivity value. The lowest values (of the order of 10^5 electrostatic units) mentioned above were obtained on the solid granite or slate subsoils found at some of the sites.

The concluding section of the paper illustrates in graphical form the effect of the electrical properties of the soil on the penetration of alternating currents below the surface. Curves are plotted for certain of the sites from which samples of soil were obtained for measurement. These curves illustrate the fact that while at a frequency of 100 kilocycles per sec. a few per cent of the current at the surface may penetrate to a depth of 20 metres (over 60 ft.), at a frequency of 10 000 kilocycles per sec. the current is practically confined to the first 3 or 4 metres of depth. The effect of such current penetration on the field at the surface due to an electric wave being propagated along this surface is a subject that must remain for further investigation.

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(1) INTRODUCTION.

A knowledge of the electrical properties of the earth's surface is of considerable importance in physics and electrical engineering as well as in radio communication. Many investigators have employed electrical methods in exploring the ground for the presence of oil, minerals, etc., and some of these have become more or less standardized as useful tools in the general study of geophysics. In electrical engineering it is important to have efficient earth connections to the supply and distribution systems, and it is now well known that the resistance of such a connection is directly dependent upon the conductivity of the ground. In radio communication the electrical properties of the earth enter directly into the design of the transmitting installation, even in the case of a station employing an antenna array with no direct connection to earth. Further, the conductivity and dielectric constant of the ground are the dominating factors in determining the effective service area of broadcasting stations, in which the bulk of the communication is effected by the electric waves travelling along the surface of the earth. Finally, the efficiency of the receiving station is dependent upon the good conductivity of the ground upon which it is erected. The extending use of shorter wavelengths, with its consequent increase in the attenuation of the ground waves, has emphasized the importance of obtaining an accurate knowledge of the electrical properties of the ground. In addition to these applications it must be remembered that the soil physicist is interested in all the physical properties of various types of soil, and in particular in those which will provide him with any information as to the structural nature of the soil.

In order to form a clear idea as to the state of present knowledge on this subject, the first portion of the paper presents a summary of the literature indicating what information has already been obtained on the electrical properties of the earth. Various alternating-current methods have been used in this research, and, from the author's point of view, attention has been directed chiefly to the radio-frequency end of the spectrum, although the relevant material available at power frequencies has not been neglected.

The classical electromagnetic equations express the mode of propagation of electrical energy through a non-conducting medium having assigned values of dielectric constant and permeability, the velocity of propagation being calculable in terms of these quantities. If the medium has a finite conductivity, it is necessary to modify the equations by replacing the dielectric constant κ by the quantity

$$\kappa' = \kappa\left[1 - j \, . \, 2\sigma/(\kappa f)\right] \quad . \quad . \quad . \quad . \quad (1)$$

where σ is the conductivity, κ the dielectric constant, and f the frequency.

Defined in this way, the quantity κ' may be employed in all the equations required for the specification of the flow of alternating currents in conducting dielectrics. The factor j merely indicates the difference in phase of the conductance and displacement components of the current. It may be noted that in the extreme case in which $2\sigma/(\kappa f)$ is very small compared with unity, the conductivity has a negligible effect. Similarly when $2\sigma/(\kappa f)$ is large compared with unity the effect of the dielectric constant is unimportant in determining the flow of current.

It will be evident from such considerations that in order to ascertain the effect of soil upon alternating currents flowing therein, whether applied direct or whether resulting from the passage of electric waves through or over it, it will be necessary to have a knowledge of the two quantities κ and σ at the frequency of the currents in question.

In the publications of previous writers there is some divergence of opinion as to whether the conductivity is more conveniently expressed in electrostatic or electromagnetic units, or as the reciprocal of a resistivity in ohm-cm (i.e. ohms per cm cube). In the author's opinion the procedure to adopt is that of expressing σ in electrostatic units, when the quantity may be substituted directly into any equations (such as those given above) involving κ or κ', which are almost invariably expressed in electrostatic units. If electromagnetic units are employed for σ, it is necessary to use a conversion factor for the ratio of the units (c^2), which introduces an unnecessary quantity into all the formulæ involved. In order to facilitate the conversion of the quantities in the mind of the reader, the following relations are given, assuming the velocity of light to be given by $c = 3 \times 10^{10}$ cm per sec.:—

$$\sigma_{e.s.u.} = \sigma_{e.m.u.} \times 9 \times 10^{20}$$
$$\sigma_{e.s.u.} = (1/\rho) \times 9 \times 10^{11}$$

where ρ is the resistivity in ohms per cm cube.

(2) PREVIOUS WORK ON THE ELECTRICAL PROPERTIES OF SOIL.

(*a*) *Early Investigations.*

Much pioneer work in the study of the transmission of electric waves over or through a conducting dielectric was included in the classical researches of Clerk Maxwell, Oliver Heaviside, and Sir J. J. Thomson. After it had been demonstrated that electric waves could be transmitted to appreciable distances over the earth's surface, attention was devoted by several investigators to the effect of the earth in wireless communication. Sir Oliver Lodge,[*] in 1899, demonstrated the application of classical electromagnetic theory to this problem, while Brylinsky[†] and W. Burstyn[‡] later studied the penetration of alternating currents into soil and sea-water. Confirmation of the fact that the earth played a part in the propagation of wireless waves was provided by the experiments of J. S. Sachs[§] in 1905, who found that the radiation from a transmitter increased as the aerial was raised above the earth's surface.

A mathematical investigation of the propagation of electric waves along the earth's surface was published by A. Sommerfeld[||] in 1909, and this paper still remains the most complete theoretical treatment of the subject. In order to reduce Sommerfeld's formulæ to numerical quantities, attempts were made to obtain measurements of the conductivity of soil materials at audio frequencies by several workers, notably H. Lowy[¶] and K. Uller[**] in 1911. Some measurements made by Eickhoff are also contained in J. Zenneck's paper[††] on the propagation of waves along the earth's surface. Eickhoff studied the variation of conductivity with moisture content and found that for garden soil the value rose from $0{\cdot}5 \times 10^6$ to $1{\cdot}5 \times 10^8$ e.s.u. (electrostatic units) as the moisture content was increased from 3 to 17 per cent. In most of these cases, however, the conductivity measurements were made on artificially treated specimens of soil, and investigations carried out during the past 10 years have shown that these results are of little practical significance in radio technique at the present time. The values obtained were, however, quoted in textbooks until comparatively recently, and they have formed the basis of several investigations of the shape of the electric field in a wave transmitted along the earth's surface, e.g. those of J. Zenneck[‡‡] and F. Hack.[§§]

(*b*) *Direct Measurement of Electrical Constants at High and Low Frequencies.*

Probably the simplest method of ascertaining the conductivity of a material is to measure the current which flows under the application of a given voltage. When a direct-current voltage is applied to a specimen of soil in this manner, the effects obtained are complicated by the occurrence of polarization phenomena giving rise to reverse electromotive forces. These effects arise from the fact that the conduction is partly electrolytic in nature owing to the moisture content of the soil. For this reason measurements of soil conductivity obtained by the application of direct current are not likely to yield reliable results suitable for use in connection with alternating currents of high frequency.

With a view to overcoming this difficulty, while still retaining the use of a d.c. generator and measuring instrument, O. H. Gish and W. J. Rooney[||||] have used a commutator giving 60 reversals per sec. to convert the direct current into alternating current before its application to the soil, at the same time including a second commutator to act as a mechanical rectifier in the detector circuit to restore the alternating current to direct current. The subject was studied chiefly from a geological-survey standpoint, and the results obtained give values of the average resistivity of the ground to depths varying from 1 or 2 down to several hundred metres. The measurements carried out at Watheroo, Western Australia,[*] show that beneath a surface of high-resistivity sand ($\sigma < 10^6$ e.s.u.) there is a region of unusually high conductivity, the average value of which to a depth of 100 metres is about 13×10^8 e.s.u., decreasing to an average of $1{\cdot}4 \times 10^8$ e.s.u. for a depth of 600 metres. G. F. Tagg[†] has described the application of this arrangement to a megger-type earth-tester, together with results obtained in this country in a geophysical survey of earth resistivity. At the frequency of 50 cycles per sec. used in this investigation the average value of the conductivity of the surface soil for a site in Southern England was about $0{\cdot}5 \times 10^8$ e.s.u., equivalent to a resistivity of nearly 18 000 ohm-cm. Experimental measurements made for depths of a few hundred feet gave considerable variation of the conductivity with depth and the nature of the subsoil.

An alternative method of deducing the conductivity of the ground at power and telephonic frequencies is based upon a measurement of the impedance of two earthed circuits. Some recent results obtained in this manner have been recorded by J. Collard,[‡] and these show that at a frequency of 3 000 cycles per sec. the effective conductivity was 36×10^8 e.s.u. at one site on the English coast, and $1{\cdot}5 \times 10^8$ e.s.u. at two other sites, one of which was inland.

In a more comprehensive investigation P. J. Higgs[§] has studied the conductivity of surface soil in the neighbourhood of the National Physical Laboratory (N.P.L.) by direct measurement with alternating current of a frequency of 50 cycles per sec. Under conditions of normal temperature and moisture content for surface soil, Higgs gives a conductivity value of the order of $0{\cdot}75 \times 10^8$ e.s.u. (resistivity = 12 000 ohm-cm), the lower sandy soil at a depth of about 2 ft. having about twice this conductivity. His results show also that the conductivity increases with the temperature, the coefficient being about 3 per cent per deg. C. This is consistent with the idea that the conductivity of moist soil is electrolytic in nature.

A description of some direct measurements of the electrical properties of soil carried out at radio frequencies was published by J. A. Ratcliffe and F. G. W. White[||] in 1930. In this case the soil under examination formed the dielectric between the plates of a cylindrical condenser, and the effective capacitance and resistance of this condenser were measured at various radio frequencies up to about 4 million cycles per sec. The values of apparent dielectric constant for samples of soil from two different sites (Cambridge and Daventry) in England decreased from over 40 at a frequency of 200 kilocycles per sec. to about 12 at 3 000 kilocycles per sec. The conductivity results given by Ratcliffe and White show an erratic variation with frequency, but they lie between limiting values of about $0{\cdot}2 \times 10^8$ and $0{\cdot}5 \times 10^8$ e.s.u. for the same samples of soil. These samples were taken from the surface and were presumably of normal moisture content. On drying them out, it was found that the dielectric constant and conductivity had decreased to about 5 and $0 \cdot 5 \times 10^6$ e.s.u. respectively.

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[*] See Reference (1). [†] *Ibid.*, (2). [‡] *Ibid.*, (3). [§] *Ibid.*, (4).
[||] *Ibid.*, (5). [¶] *Ibid.*, (6). [**] *Ibid.*, (7). [††] *Ibid.*, (8).
[‡‡] *Ibid.*, (8). [§§] *Ibid.*, (9). [||||] *Ibid.*, (10), (11), and (12).

[*] See Reference (12). [†] *Ibid.*, (13).
[‡] *Ibid.*, (14). [§] *Ibid.*, (15). [||] *Ibid.*, (16).

More recently, M. J. O. Strutt[*] has also studied the conductivity of soil by direct observation of the current flowing through a "soil condenser" under the application of a given voltage. Over a range of frequencies of from 20 to 500 000 cycles per sec. the conductivity of surface field soil (presumably from Eindhoven, Holland), increased from $0 \cdot 33 \times 10^8$ to $0 \cdot 44 \times 10^8$ e.s.u.

A laboratory method in which a condenser containing a sample of soil is matched with an equivalent electrical circuit comprising a condenser and shunt resistance, both variable, has been employed by C. B. Feldman[†] at wavelengths between 8 and 32 metres (frequencies $37 \cdot 5$ and $9 \cdot 4$ megacycles per sec.). A gold-plated concentric-cylinder type of condenser was used having a capacitance—with air as the dielectric—of 15 $\mu\mu$F. To simulate the natural degree of compactness of earth, a sampling cup was used to remove from the natural state an amount just sufficient to fill the cell. For a site at Holmdel, New Jersey, U.S.A., the topsoil, consisting of black loam, showed a conductivity of from $0 \cdot 8 \times 10^8$ to $1 \cdot 5 \times 10^8$ e.s.u., the corresponding dielectric constant varying from 12 to 23. The higher values in each case were obtained when the soil was "very wet." For the clay subsoil found at a depth of 3 ft., somewhat higher values ($1 \cdot 9 \times 10^8$ and 28 respectively) were obtained. At the Netcong, New Jersey, site, where the soil to a depth of $1\frac{1}{2}$ ft. comprised dry clay with stone chips, the conductivity ranged from $0 \cdot 1 \times 10^8$ to $0 \cdot 3 \times 10^8$ e.s.u. and the dielectric constant from 7 to 10. Most of the measurements at each site showed an increase of conductivity, of the order of 10 per cent, as the wavelength was reduced from 32 to 8 metres, while the dielectric constant indicated a somewhat larger decrease with reduction of wavelength. No records of moisture content or of temperature appear to have been made in connection with these measurements, although, as will be seen later in this paper, both these factors are of importance in the carrying-out of accurate measurements of soil constants.

(c) *Measurements at Radio Frequencies by Wave-Tilt Methods.*

Among the earliest methods employed at radio frequencies to determine an effective practical value for the conductivity of soil was that of the tilting-rod aerial, used by R. H. Barfield and the present author[‡] in some measurements carried out in 1924. When electric waves are propagated over the surface of a perfect conductor the electric force is always at right angles to the surface. In the case of imperfect conductivity, however, the electric force is subjected to a forward tilt from the normal position, and when both the dielectric constant and the conductivity are of importance the electric field is of the form of a rotating vector terminating in an elliptical locus in the plane of propagation of the wave. The angle of forward tilt of the electric field or of the major axis of the ellipse can be measured with a suitable rotating aerial system.

In an experimental survey carried out over a large portion of Southern England with the aid of this method, the conductivities varied from $0 \cdot 6 \times 10^8$ to $4 \cdot 7 \times 10^8$ e.s.u., but no consistent correlation was found between this value and the frequency or the nature and condition of the soil at the site of the measurements. Later measurements[*] carried out at one site (Radio Research Station, Slough) over a period of several months gave a mean value of $0 \cdot 9 \times 10^8$ e.s.u. for the conductivity at frequencies from 620 to 860 kilocycles per sec. More recently, R. H. Barfield and G. H. Munro[†] have used the same method at a frequency of 19 megacycles per sec. (wavelength 16 m), and at a site in the neighbourhood of Slough the resulting conductivity values ranged from $0 \cdot 5 \times 10^8$ to $2 \cdot 5 \times 10^8$ e.s.u.

The tilting-rod method has also been applied by Cairns[‡] in Western Australia at the site previously used by Gish and Rooney,[§] and from the results obtained he confirmed the deduction that the highly conducting subsoil was effective in determining the mode of propagation of radio waves in spite of the low conductivity of the surface sand.

An alternative method of arriving at values of earth conductivity from the tilt of the wave-front is provided by the use of the wave antenna, which has been developed in America and in this country for obtaining highly directive reception in long-distance communication. This antenna derives its signal e.m.f. from the horizontal component of the electric force in the arriving wave, and by comparing this e.m.f. with that obtained on a vertical aerial or closed loop a direct comparison may be made between the horizontal and vertical components of electric force in the arriving wave-front. In this manner[||] values of the conductivity of the ground have been deduced for Wroughton in Southern England and Cupar in Scotland as $2 \cdot 5 \times 10^8$ and $1 \cdot 0 \times 10^8$ e.s.u respectively, while at Houlton, Maine, U.S.A., a value of $0 \cdot 14 \times 10^8$ e.s.u. was obtained. In each case the frequency employed was 60 kilocycles per sec.

One of the outstanding advantages of the wave-tilt method of conductivity determination described in this section, is that it gives the effective value of the constants for the earth at the site of the measurements. The varying contributions of the layers of soil of different depths are correctly integrated for the frequency employed, and the results obtained are thus directly applicable to the practical case for which the data are required. Laboratory measurements on isolated samples can be carried out to a higher degree of accuracy, but it is necessary to take account of possible variations with depth before practical application of the results can be made. This matter is discussed further in Section (6).

(d) *Evaluation of Conductivity from Field-Attenuation Measurements.*

When electric waves are radiated from a transmitting station the intensity of the field at any point is a function of the distance of the point from the source, the wavelength or frequency employed, and the electrical constants of the earth. Various theoretical and empirical laws have been given from time to time connecting the field intensity with the distance of transmission, and of these the most comprehensive theoretical analysis was that given by Sommerfeld* in 1909.

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[*] See Reference (17).

[†] *Ibid.*, (18).

[‡] *Ibid.*, (19).

[*] See Reference (20).

[†] *Ibid.*, (21).

[‡] *Ibid.*, (22).

[§] *Ibid.*, (10).

Ibid., (23).

On the experimental side Ratcliffe and Barnett† measured field-attenuation curves for wave-frequencies of 190 and 830 kilocycles per sec., and, by a comparison with similar curves calculated from Sommerfeld's theory, conductivity values of $1 \cdot 6 \times 10^8$ and $0 \cdot 5 \times 10^8$ e.s.u. respectively were obtained for the above frequencies. Barfield‡ in 1926 measured attenuation curves at distances up to 150 km in various directions radiating from one of the London broadcasting stations at a carrier-wave frequency of 825 kilocycles per sec., and obtained values of the earth's conductivity ranging from $0 \cdot 2 \times 10^8$ to $1 \cdot 0 \times 10^8$ e.s.u. From subsidiary experiments, Barfield concluded that the differences in conductivity in different directions were due to the varying densities of trees in the paths of transmission. These investigations were continued by G. H. Munro§ for the higher frequency of 12 megacycles per sec. (wavelength 24 metres), and conductivity values of from $0 \cdot 8 \times 10^8$ to 3×10^8 e.s.u. were deduced for ground in the vicinity of Slough.

The two great disadvantages of these attenuation methods of deriving values of the earth's electrical constants are, first, that the method employed rests upon an assumed theory of the process of attenuation; and secondly, that only an average value can be obtained for the soil covering the whole path of transmission. As far as the first point is concerned, it is only comparatively recently that it has been generally agreed that Sommerfeld's theory, already referred to, covers the case of the propagation of waves along the earth's surface, although modifications to this theory have been suggested by B. Rolf.‖ Using this modified theory, Rolf has deduced values of the electrical constants of soil in various parts of Sweden from field-strength measurements made by Lemoine. Around the Motala and Karlsborg stations working at frequencies of about 230 kilocycles per sec. (wavelength 1 300 metres), the conductivity is low, varying from $0 \cdot 05 \times 10^8$ to $0 \cdot 09 \times 10^8$ e.s.u., the corresponding dielectric constant being 15. Around Malmo, and for frequencies of about 1 000 kilocycles per sec., the conductivity is about $1 \cdot 3 \times 10^8$ e.s.u. while the dielectric constant is 10.

Rolf's calculations from Sommerfeld's analysis have also been used by S. S. Kirby and R. A. Norton¶ in connection with field-attenuation measurements which they have conducted on various transmitting stations in America. For wave-frequencies between 600 and 1 000 kilocycles per sec. the deduced values of earth conductivity ranged from $0 \cdot 3 \times 10^8$ to $1 \cdot 0 \times 10^8$ e.s.u., the average value of the dielectric constant being 13. While some little experimental evidence has been put forward in favour of Rolf's modification, it is considered that values of the electrical constants of the earth should preferably be obtained in other ways and then used for insertion in the appropriate formulæ to check the theoretical analysis against experimental attenuation curves.

In the course of an investigation of the field intensities around some Australian broadcasting stations, R. O. Cherry* has been able to estimate the effective conductivity of the ground over which his experiments were carried out. His results for the case of Melbourne on a carrier-wave frequency of 810 kilocycles per sec. gave a conductivity of $3 \cdot 6 \times 10^8$ e.s.u. in a south-westerly direction over bare ground with few trees; in a south-easterly direction, where the ground is covered with low scrub and light timber, the value was $3 \cdot 0 \times 10^8$ e.s.u.; while in the northerly direction, where the ground is heavily timbered, a lower value of about $0 \cdot 9 \times 10^8$ e.s.u. was obtained. This decrease in effective conductivity with increase in the density of trees is in good agreement with Barfield's results obtained in England and referred to above. The results obtained by Cherry around Hobart, Tasmania, at 580 kilocycles per sec. indicated a bare-ground conductivity of $0 \cdot 45 \times 10^8$ e.s.u.

(e) *Miscellaneous Results at Ultra-Short Wavelengths.*

In the investigations described in the preceding sections the maximum frequency employed was in the neighbourhood of 10 000 kilocycles per sec., while the majority of the measurements were carried out at 1 000 kilocycles per sec. or less. The resulting value of the conductivity obtained for various sites in this country has been found to be of the order of 10^8 e.s.u. For this conductivity the quantity $2\sigma/f$ is equal to 200 at a frequency of 1 000 kilocycles per sec., and from the reasoning given in Section (2) it will be evident that unless the dielectric constant κ has a value approaching 100, the value of $2\sigma/(\kappa f)$ will be so high that κ will play only a negligible part in the propagation of waves over or through the earth medium. If the value of σ is found to be independent of the frequency f, then as f is increased the value of $2\sigma/f$ will decrease; so that it might be expected that at a sufficiently high frequency the dielectric constant would play a prominent, and even a major, part in determining the effect of the earth on wave propagation. This fact, in conjunction with the modern widespread use of short waves for communication purposes, adds considerable interest and importance to the study of the earth's electrical properties at very high radio frequencies.

M. J. O. Strutt† has made soil-conductivity determinations (in Holland) at various frequencies between $0 \cdot 5 \times 10^6$ and 20×10^6 cycles per sec. by measuring the attenuation along two parallel wires, 100 metres in length, buried in the ground 2 cm apart at a depth of 30 cm. It was found that the amplitude of the waves on the wires decreased according to an exponential law, which indicated a conductivity of $0 \cdot 45 \times 10^8$ e.s.u. and a dielectric constant of 10.

In the course of an investigation of the influence of the earth on the radiation from an antenna, Strutt‡ also developed a method of measuring the conductivity of the earth, based upon radiation measurements made with elevated transmitting and receiving apparatus. Using a wavelength of $1 \cdot 4$ metres (frequency 210 megacycles per sec.), a value of conductivity in excess of 10×10^8 e.s.u. was obtained for soil which at lower frequencies possessed a normal value of about 1×10^8 e.s.u.

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* See Reference (5).
† *Ibid.*, (24).
‡ *Ibid.*, (25).
§ *Ibid.*, (21).
‖ *Ibid.*, (26).
¶ *Ibid.*, (27).

* See Reference (28).
† *Ibid.*, (17).
‡ *Ibid.*, (29).

During the past two or three years J. S. McPetrie and the author have investigated the attenuation of ultra-short waves when transmitted along the earth's surface, largely with the object of obtaining more definite knowledge of the electrical constants of the earth at very high radio frequencies. In the first experiments* a series of field-attenuation measurements were made for frequencies between 30 and 60 megacycles per sec. (wavelengths 10 to 5 metres), and these indicated that the value of the conductivity of field soil at Teddington lies between 5×10^8 and 30×10^8 e.s.u. for the above frequencies. A later paper† describes the extension of this work to a frequency of 190 megacycles per sec. (wavelength 1·6 metres). At this short wavelength the type of attenuation curve obtained depends to a large extent upon the height of the transmitting and receiving apparatus above the surface of the earth, interference effects being obtained in a manner similar to that described by Strutt.‡ Comparisons between experimental and theoretical attenuation curves suggested in this case an effective conductivity value of about 95×10^8 e.s.u. for the same site as that used in the previous measurements.

While these values at very high frequencies must be regarded as somewhat tentative pending confirmation by further experiments, one important point has already emerged. Owing to the considerable rise in the value of the conductivity with increase of frequency the experimental methods do not enable the dielectric constant of the earth to be ascertained with any great accuracy, although a value of about 10 appears to fit the results. This is due to the fact that the value of $\kappa f/(2\sigma)$ is about 0·1 at the highest frequency employed, so that, as previously explained, the dielectric constant plays an almost negligible part in determining the flow of current in the earth or the propagation of waves over its surface.

(3) MEASUREMENT OF THE ELECTRICAL PROPERTIES OF SOIL BY A LABORATORY METHOD.

The survey of published work given in the previous section shows that in certain rather scattered frequency-ranges and for various localities, measurements of the electrical properties of soil have been made chiefly by field methods depending upon wave-propagation phenomena, and in a few cases only by laboratory methods. It was considered desirable to obtain more complete information on this subject in a systematic manner under controlled conditions, taking full advantage of the improved facilities and technique now available in the radio laboratory. In a recent paper§ the author described the application of a method of measuring resistance and reactance at radio frequencies to a preliminary study of the electrical conductivity of soil. Sufficient results were there given to show that these were substantially in agreement with such previous measurements as had actually been carried out in the field upon electric waves. In the present paper the application of this method is examined in more detail, and the investigation has been extended to the general survey of the electrical properties of the soil from a number of different sites in this country. Although interest in this matter has arisen directly from its association with radio communication, and the majority of the work was carried out at frequencies between 100 and 10 000 kilocycles per sec., the measurements have in some cases been extended through the audible range down to a power frequency of 50 cycles per sec.

The basic principle of the method employed in this work consisted in measuring the constants, capacitance, and resistance, of a fixed condenser of suitable size and shape, having for its dielectric the sample of soil under examination. From the measured values of these constants and a knowledge of the capacitance of the condenser, with air as the dielectric, the effective conductivity and dielectric constant of the soil can be calculated as follows. If C_a is the capacitance of the condenser in air, and C_s and R_s are the capacitance and shunt resistance respectively of the condenser when it is filled with soil, then the apparent dielectric constant is given by

$$\kappa = C_s/C_a \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

while the conductivity (σ) or resistivity (ρ) can be found from the relationship:—

$$\sigma = 1/\rho = 1/(4\pi C_a R_s) \quad . \quad . \quad . \quad . \quad (3)$$

Equation (2) gives the dielectric constant in electrostatic units. In equation (3), R_s is usually measured in ohms, and then, if C_a is measured in centimetres, ρ will be given in ohms per cm cube, or, more briefly, in ohm-cm. To obtain the conductivity in electrostatic units, the relationship $\sigma_{e.s.u.} = 9 \times 10^{11}/\rho$ may be employed.

At radio frequencies the measurements of resistance and reactance were carried out by the general method described by F. M. Colebrook and R. M. Wilmotte,* in the manner adopted in the work to which reference has already been made. For the lower frequencies a standard type of capacitance bridge was employed, using a telephone as the detector in the audible range and a vibration galvanometer at the power frequency of 50 cycles per sec.

(4) MEASUREMENTS ON SOIL INDICATING THE INFLUENCE OF VARIOUS FACTORS.

(a) *Practical Details.*

At the beginning of the investigation some experiments were carried out to determine the most suitable size and shape of container for the work. Consistent results were obtained for tightly rammed soil in cylindrical containers of various dimensions; and as in this condition the density of the soil in the container was found to correspond to the density of the soil just below the surface of the undisturbed grass meadow from which the sample was taken, this was assumed to be the desirable condition for the soil under test. While there was no reason to suppose that the material of the electrodes affected the results, the final containers employed were made of copper with keramot insulation. The capacitance of the container used for finely powdered sand or loam was $2 \cdot 5\ \mu\mu$F, while a larger container (used for coarse gravel, etc.) had a capacitance of $3 \cdot 2\ \mu\mu$F. It was found that repeated measurements on successive samples of soil from the same site and used under the above conditions gave consistent results to an accuracy of 10 per cent or less; in view of the relatively large variation of the electrical properties of the soil with its nature, moisture content, and temperature, as described below, this overall accuracy was considered to be quite adequate for all purposes for which the information was required. Experiments made from time to time in the course of the work showed that the measured quantities are independent of the applied voltage over a range of from 0·1 to 1·0; the majority of the measurements discussed below were made with a potential difference of about 0·5 volt across the condenser.

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* See Reference (30). † *Ibid.*, (31). ‡ *Ibid.*, (29). § *Ibid.*, (32).

* See Reference (33).

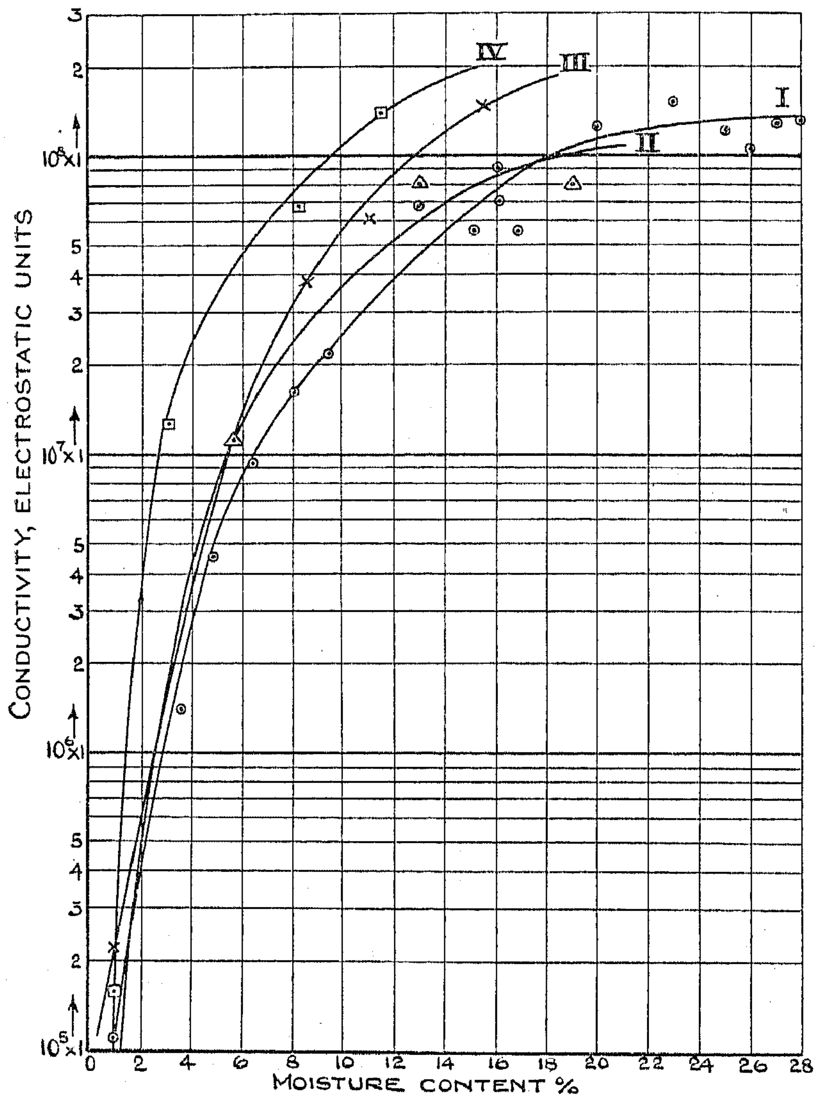

FIG. 1.—Relation between conductivity and moisture content for soils from sites Nos. I to IV (N.P.L.) at a frequency of 1 200 kilocycles per sec.

(*b*) *Dependence of Electrical Properties on Moisture Content.*

In a previous paper it was shown that the electrical properties of soil and their variation with frequency depend upon the moisture content* of the specimen under examination. For example, Fig. 1 illustrates a set of conductivity measurements made at a frequency of 1 200 kilocycles per sec. on samples of garden loam and field soil from four different sites within the N.P.L. It is seen that the conductivity of the dry soil is of the order of 10^5 e.s.u. (9 megohms per cm cube), while at a moisture content of between 12 and 26 per cent the conductivity approaches a limiting value of between 10^8 and 2×10^8 e.s.u. (9 000 to 4 500 ohms per cm cube). The corresponding values of dielectric constant are shown in Fig. 2, from which it is seen that the value is 3 or 4 for the dry soil, rising to 30 or 40 for the very moist soil. It is worthy of note that the limiting values to which the curves in Figs. 1 and 2 approach, are for moisture contents which may be termed normal values for the soil in question. For example, in the case of site 1 at the N.P.L. the moisture content of the surface soil was measured every day over a period of 12 months, and was found to lie between 16 and 30 per cent over the greater part of the year. It was only during periods of heavy rain that the upper limit was exceeded, and, while a few samples having a content of 39 per cent were on occasions taken while it was raining, the value rapidly decreased to 30 per cent when the rain stopped. In the other direction the moisture in the surface soil decreased steadily during the dry summer season, but it was only after several weeks of hot dry weather that the moisture content reached its lower limit of 4 per cent. This condition, however, prevailed for only a few inches below the surface. Samples taken during this period from a depth of 1 ft. gave a minimum moisture-content value of 16 per cent.

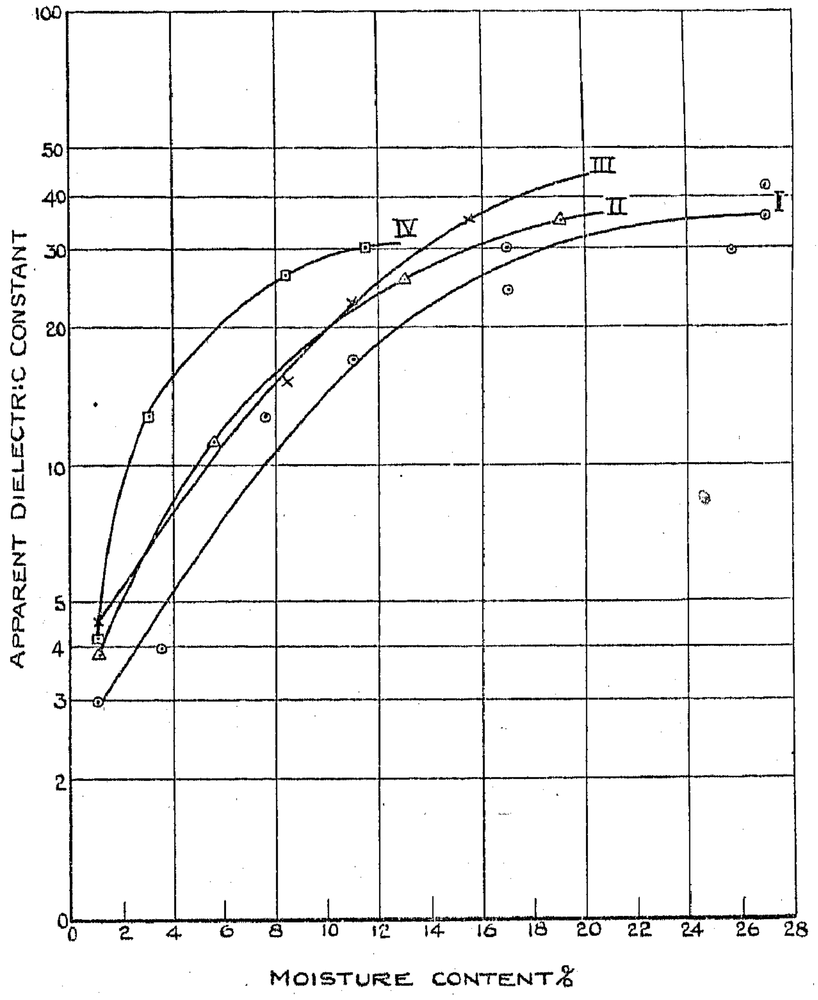

FIG. 2.—Relation between apparent dielectric constant and moisture content for soils from Sites Nos. I to IV (N.P.L.) at a frequency of 1 200 kilocycles per sec.

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* In this work, the moisture content was determined by placing a weighed sample of soil for 24 hours in an electric oven, the temperature of which was maintained at just over 100° C. The loss of weight was taken to be that of the moisture originally contained in the sample, and the ratio of this to the weight of the dry soil is given as the percentage moisture content.

This retention of the moisture at a short distance below the surface indicates that as the surface soil dries out there will not necessarily be any marked effect on wave propagation. For, as the surface soil dries out, the depth of penetration of the electric waves will increase slightly into the more moist, and thus better-conducting, subsoil; and this factor will tend to counteract appreciably the effect of any departure of the moisture content of the soil from its normal value on the waves travelling along its surface.

(*c*) *Effect of Frequency on Electrical Properties.*

The effect on the electrical properties of soil of varying the frequency was found to depend upon the moisture content. For example, in the case of the soil from site I referred to above, when the moisture was reduced to less than 1 per cent by artificial drying, the conductivity increased from about 10^5 e.s.u. at a frequency of 1 000 kilocycles per sec. to about 9 times this value at 10 000 kilocycles per sec. As the moisture content is increased this variation with frequency diminishes considerably, although it is still perceptible for moist soil at the higher frequencies. The dielectric constant behaves in a different manner. At low moisture-contents there is practically no variation of the value with frequency, while at a normal moisture-content of about 26 per cent the dielectric constant decreases from about 90 at 100 kilocycles per sec. to 25 at 10 000 kilocycles per sec.

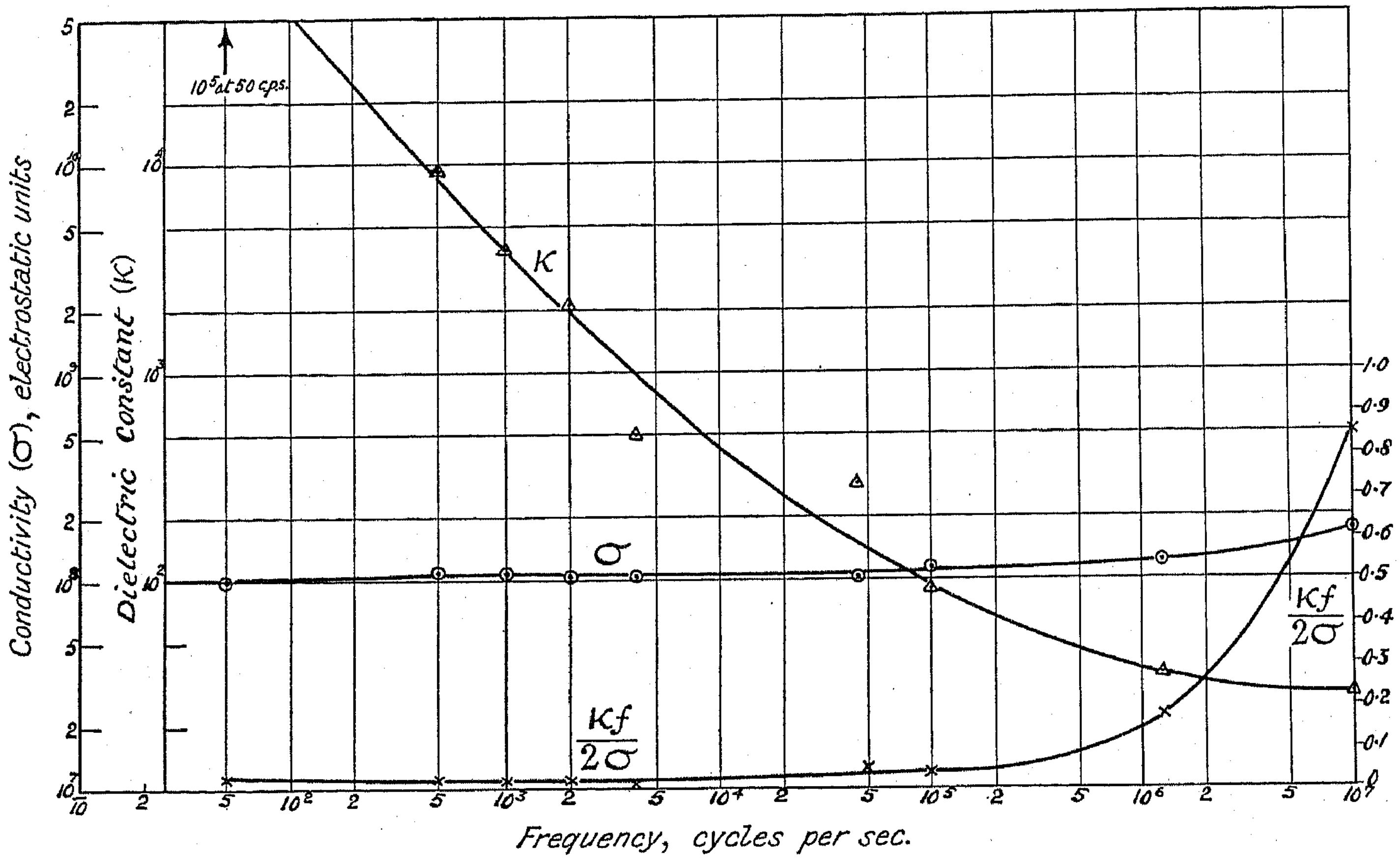

FIG. 3.—Results of laboratory measurements of electrical properties of surface soil from N.P.L. (Site No. I) at frequencies between 50 and 10^7 cycles per sec. Moisture content, 25 per cent.

In order to explore this matter further, a few samples of soil were subjected to measurement over a frequency range which was extended in the lower direction to 50 cycles per sec. The result of such a typical series of measurements is illustrated in Fig. 3. It is seen that for frequencies below 1 000 kilocycles per sec. the conductivity does not vary appreciably, and the value obtained at 50 cycles per sec. agrees with that previously obtained by Higgs* for soil at the N.P.L. At a frequency above 1 000 kilocycles per sec. there is a slight rise in the conductivity, which lends some confirmation to the high values experienced during field measurements at the N.P.L. on ultra-short wavelengths.† Over the same range the dielectric constant appears to attain the very high value of 100 000 at a frequency of 50 cycles per sec., decreasing continuously to a value of about 30 at 10 000 kilocycles per sec.

Such apparently abnormal values of the dielectric constant have been previously experienced in the study of solid dielectrics, more particularly with electrolytes, and the effects have been interpreted as being caused by the formation of a polarization film of molecular thickness over the surface of the electrodes.‡ This suggestion was recently explored in connection with a study of the electrical properties of sea water,§ and was found to be useful in indicating that the true dielectric constant of this electrolyte is probably about 80, although the apparent values as measured ranged up to several million at audio frequencies. In the case of the soil measurements the method of treatment based upon the above suggestion was not found to give similar results for the evaluation of the true dielectric constant. A notable point of difference between the two cases is that for soil the measured values of the dielectric constant appeared to be independent of the dimensions of the container to a large extent, whereas for the sea water the apparent value varied in a ratio of 2 or 3 to 1 for different lengths of container. In the soil case, any polarization phenomena are likely to be complicated

* See Reference (15). † *Ibid.*, (30). ‡ *Ibid.*, (34). § *Ibid.*, (35).

by the inherent granular structure of the material, which may thus only loosely be regarded as similar in behaviour to an electrolyte.

The extent to which the dielectric constant in comparison with the conductivity plays a part in determining the flow of an alternating current, depends upon the value of the quantity $\kappa f/(2\sigma)$, as already explained. Now in Fig. 3 the lowest curve gives the value of this quantity over the whole range of frequencies examined. It is seen that, even with the very high values of dielectric constant measured at the lower frequencies, the above quantity is less than 0·1 for all frequencies below 1 000 kilocycles per sec. It is thus evident that the dielectric constant plays only a small, if not negligible, part in the determination of current flow in soil over this range of frequencies, and for this reason it was not considered expedient to pursue the study of the matter further at this stage. For the same reason the measurement of the dielectric constant is much more difficult than that of the conductivity, and the accuracy of the results discussed above is not considered to be high. As the frequency increases from 1 000 to 10 000 kilocycles per sec., however, the value of $\kappa f/(2\sigma)$ is seen to increase to values of the order of unity, and it is therefore in this region—and possibly at higher frequencies—that the matter requires further study.

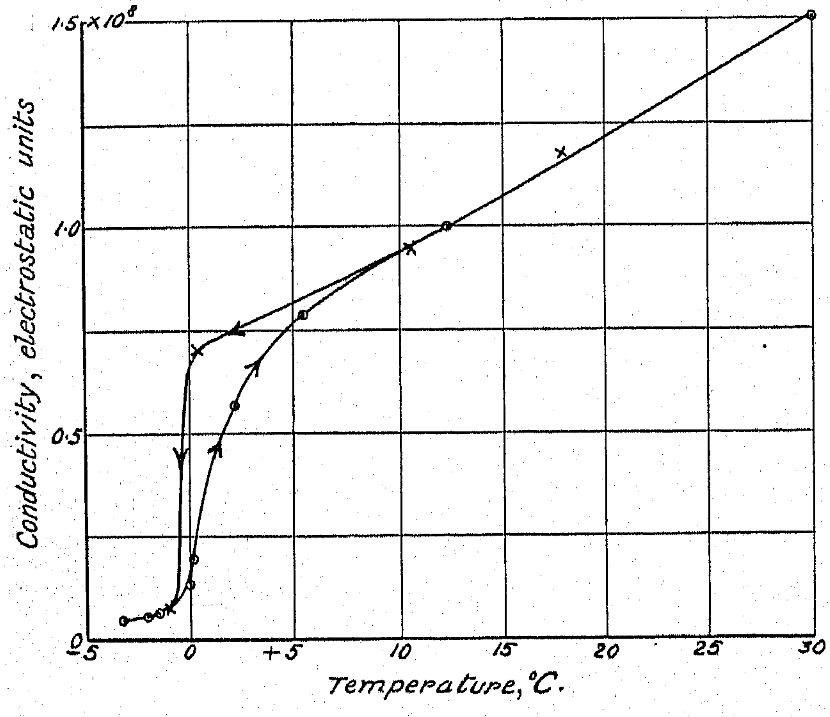

FIG. 4.—Variation of conductivity with temperature of normal sample of soil from Site No. I (N.P.L.).
Frequency = 1 200 kilocycles per sec.

(*d*) *Effect of Temperature on Soil Constants.*

In the course of his work at a frequency of 50 cycles per sec., Higgs* measured the conductivity of the soil at temperatures between − 15° C. and + 20° C. With a view to ascertaining the corresponding values at radio frequencies a sample of the loam from site I at the N.P.L. was subjected to a temperature variation from − 3° to + 30° C., while the electrical measurements were made at a frequency of 1 200 kilocycles per sec. The results obtained in this case are shown in Figs. 4 and 5, which refer to the conductivity and dielectric constant respectively. These diagrams show very clearly the sudden change in the values of these constants which occurs as the temperature passes through the freezing point of water. In the case of the conductivity curve (Fig. 4) the temperature at which the change takes place appears to depend somewhat upon the direction of the temperature-change. Although precautions were taken to ensure uniformity of temperature throughout the sample at the time the measurements were made, it is just possible that this effect was due to excessive lag in the attainment of thermal equilibrium. Over the straight part of the curve, between temperatures of 5° and 30° C., the mean temperature coefficient is 2·3 per cent per deg. C., referred to the value at 20° C. Turning to Fig. 5, it is seen that while the dielectric constant appears to be reasonably independent of temperature over the range 1° to 20° C., there is a sudden change in the neighbourhood of the freezing point, where the value drops from about 45 at + 1° C. to 14 at − 3° C.

In considering this curve it is interesting to observe that while the dielectric constant of pure water is nearly 80 at all frequencies up to at least 150 million cycles per sec., the value for ice is only about 4. An experimental check of this sudden change on passing through the freezing point was carried out in connection with the present investigation, the frequency employed being 1 200 kilocycles per sec.

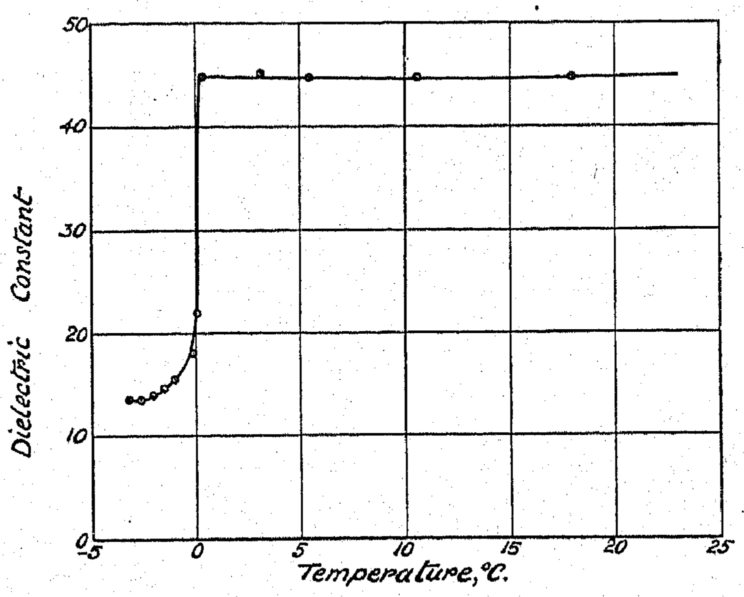

FIG. 5.—Variation of dielectric constant with temperature of normal sample of soil from Site No. I (N.P.L.).
Frequency = 1 200 kilocycles per sec.

During the course of the experimental measurements described in Section (5) below, the temperature coefficient was measured for a few other samples of different types of soil, also at a frequency of 1 200 kilocycles per sec. The results obtained are given in Table 1, which includes the results for the N.P.L. sample referred to above.

It will be seen from these typical measurements that the temperature coefficients of conductivity of different types of soil lie within the range 2–2·5 per cent per deg. C. Since the normal seasonal variation of ground temperature in this country is over 30 deg. C., it will be appreciated that temperature variation alone can account for a change in conductivity of the open ground approaching 100 per cent. In this connection, as with the moisture-content case referred to above, it must be remembered that the surface variations are not completely followed by the temperature of the ground below the surface, and that the variation of the effective conductivity of the ground with surface temperature will depend upon the depth to which the electric waves penetrate the earth. Measurements of thermal variation with depth have shown that while a diurnal variation of 20 deg. C. at the surface produces a change of only 1·4 deg. C. at about 1 ft., a seasonal change of 30 deg. C. at the surface produces a variation of about 20 deg. C. at a depth of 3 ft., and of 0·3 deg. C. at about 30 ft. It is likely that the effective depth of soil involved in wave propagation is only a few feet, particularly in the case of short wavelengths, and this being so the seasonal variation of temperature and the consequent change in conductivity will be fairly large. In view of this uncontrollable condition which is involved in the transmission of electric waves, it is considered that the limitation of accuracy of the measurements described in this paper to the order of 10 per cent is not of serious importance in the application of results to practical communication.

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* See Reference (15).

TABLE 1.

Temperature Coefficients of Conductivity of Various Types of Soils.

Site	Type of soil	Conductivity (in e.s.u.) at 20° C.		Temperature coefficient of conductivity at 20° C.
				per cent per deg. C.
N.P.L. ..	Sandy loam	1·2	$\times 10^8$	2·3
Daventry ..	Brown sand	0·11		2·2
Dousland ..	Dark brown loam	0·26		2·1
Washford Cross	Red-brown clay	3·1		2·3

(5) AN ELECTRICAL SURVEY OF THE SOIL IN DIFFERENT PARTS OF GREAT BRITAIN.

(a) *Scope and Method of Investigation.*

With the co-operation of the British Broadcasting Corporation and the Post Office, the author has been able to investigate the electrical properties of samples of soil obtained from 12 different sites in England and Scotland. This study was not limited to the surface soil, as samples were obtained from each site at various depths down to 10 ft.; while at the Midland Regional Station site, near Droitwich, the opportunity was provided of obtaining samples at greater depths down to 300 ft. As each sample of soil was taken out at the site it was sealed up in a glass jar and despatched to Teddington. Only two or three samples per day were sent in this manner, so that there was no undue delay in carrying out the measurements. Furthermore, the excavation to the required depth was arranged in correct daily amounts so as to minimize the effects of exposure of the subsoil at the actual site. When the samples comprised loose soil, sand, or clay, suitable for packing in the measuring condenser, the moisture content was determined immediately after their receipt at the Laboratory. On the same day the electrical measurements were carried out at frequencies of 1, 100, 1 200, and 10 000 kilocycles per sec. In cases where the subsoil comprised solid materials, such as slate or granite, these were machined into small slabs, and sheets of tinfoil were affixed to opposite faces to form electrodes for measurement purposes.

The samples from the Post Office stations were measured during August and September, 1932, and those from the majority of the B.B.C. stations during October and November, 1932, while the samples from the 300-ft. bore at Droitwich were obtained during February and March, 1933. To complete the series of measurements, samples at depths down to 10 ft. were obtained from a site at the N.P.L. during January, 1933.

A summary of all the results obtained in this study is given in Table 2, which includes the geological classification of each site and a brief description of the nature of the soil obtained at each depth. The moisture content is given in the customary manner as the percentage (by weight) of water to dry soil. The majority of the measurements were made at a room temperature of from 17° to 21° C., but the conductivity measurements given in the Table have been corrected to a temperature of 20° C., using the mean coefficient of 2·3 per cent per deg. C. as determined experimentally for several samples of soil (see Section 4*c*).

(b) *Conductivity Values.*

It will be observed from Table 2 that the conductivity of surface soil at a frequency of, say, 1 200 kilocycles per sec., varies from $0\cdot16 \times 10^8$ at Merrivale to $4\cdot0 \times 10^8$ at Tatsfield. At the former site the conductivity decreases very rapidly with depth to a value of $2\cdot4 \times 10^5$ owing to the presence of solid granite, while at Tatsfield the conductivity varies with depth only to a minimum of $1\cdot6 \times 10^8$. The results of similar measurements at the above frequency for other sites lie between limiting values of $1\cdot6 \times 10^5$ and about 10^{10}. The conductivity of the sample definitely increases with the frequency in all cases, but the amount of the variation is considerably greater for the poorly-conducting and solid samples than for the more highly-conducting soils.

A point of some interest is the rapid change in conductivity at sites not far apart. For example, at Rugby for two sites only 20 yards apart, values of $3\cdot9 \times 10^8$ and $0\cdot70 \times 10^8$ respectively were obtained for surface samples at a frequency of 1 200 kilocycles per sec. The moisture content associated with the first site was nearly 3 times that found at the second, and was probably in part responsible for the high conductivity. Thus for surface soil of the same nature the moisture content, and hence the conductivity, may be directly dependent upon the subsoil, apart from any contribution of the subsoil to the effective conductivity at different depths. On the other hand the general conductivity at Rugby ranges from about $0\cdot7 \times 10^8$ to $9\cdot5 \times 10^8$ at the above frequency. At Daventry, about 8 miles away, the corresponding values are from $0\cdot1 \times 10^8$ to $1\cdot1 \times 10^8$.

In general it may be said that the clays show a high

TABLE 2.

Measurements of Samples of Soil taken from Different Depths at Various Sites.

Sample No.	Site	Geological classification	Depth	Description of sample	Moisture content	Conductivity (in e.s.u.) at 20° C. and at frequencies in kilocycles per sec. of:—				Apparent dielectric constant (in e.s.u.) at frequencies in kilocycles per sec. of:—	
						1	100	1 200	10 000	1 200	10 000
			ft.		per cent						
90	Rugby Radio Station (1)	Lower lias	Surface	Dark fibrous loam	60	$3\cdot0\times10^{8}$	$3\cdot4\times10^{8}$	$3\cdot9\times10^{8}$	$6\cdot0\times10^{8}$	100	55
92			1	Loam and clay	33	6·5	7·0	7·0	9·0	95	43
93			2	Clay and sand	26	7·5	8·0	8·0	12·0	105	48
94			3	Blue clay	25	8·0	9·0	9·5	11·0	95	46
95			10	Blue clay	23	6·0	6·5	7·0	8·5	60	29
97	Rugby Radio Station (2)	Lower lias	Surface	Loam	22	0·55	0·65	0·70	1·1	35	25
104			1	Loam and clay	13	0·85	0·85	1·2	1·4	32	21
105			3	Blue clay	27	6·5	7·5	8·0	13·0	125	75
106			5	Clay and sand	21	5·5	5·5	6·5	9·0	75	42
107			10	Blue clay	25	7·0	8·0	8·5	12·0	70	40
98	Baldock, Herts (P.O. Receiving Station)	Chalk	Surface	Fibrous loam	21	0·85	0·90	0·95	1·4	39	23
99			1	Chalky loam	21	0·55	0·55	0·85	0·95	41	25
100			2	Chalk	24	0·28	0·26	0·38	0·61	28	21
101			3	Chalk	27	0·65	0·70	0·80	1·0	35	29
102			5	Chalk	26	0·91	1·4	1·6	2·0	45	38
103			10	Chalk	27	1·3	1·4	1·5	1·9	44	34
108	Tatsfield, Kent (B.B.C. Receiving Station)	Upper greensand	Surface	Fibrous loam	37	2·7	3·4	4·0	5·0	80	49
109			1	Brown, sandy clay	19	2·2	2·4	2·4	3·8	39	19
110			2	Brown sand	15	1·8	2·0	2·1	3·3	33	19
111			3	Light brown sand	13	1·4	1·5	1·6	2·1	33	25
112			5	Light brown sand	20	2·3	2·3	2·5	4·0	60	37
113			10	Yellow sand	15	1·5	1·7	2·0	2·9	60	28
114	Brookmans Park, Herts (London Regional Station)	London clay	Surface	Fibrous loam	19	0·90	0·95	1·1	1·7	48	25
115			1	Stony loam	18	0·85	0·90	0·95	1·4	40	24
116			2	Light sandy clay	22	0·50	0·65	0·70	1·6	45	24
117			3	Sandy clay	22	1·1	1·2	1·5	2·9	70	33
118			5	Sandy clay	21	1·5	1·7	1·9	2·6	75	36
119			8 to 10	Clay and shingle	10	1·5	1·6	1·6	2·7	42	23

TABLE 2.—*Continued.*

Measurements of Samples of Soil taken from Different Depths at Various Sites.

Sample No.	Site	Geological classification	Depth	Description of sample	Moisture content	Conductivity (in e.s.u.) at 20° C. and at frequencies in kilocycles per sec. of:—				Apparent dielectric constant (in e.s.u.) at frequencies in kilocycles per sec. of:—	
						1	100	1 200	10 000	1 200	10 000
			ft.		per cent						
121	Daventry, Northants	Upper lias	Surface	Fibrous loam	28	$0\cdot85\times10^8$	$0\cdot95\times10^8$	$1\cdot1\times10^8$	$1\cdot6\times10^8$	48	30
122			1	Sandy loam	16	0·34	0·34	0·40	0·61	20	17
123			2	Brown sand	14	0·29	0·29	0·33	0·46	20	14
124			3	Brown sand	5·0	0·10	0·11	0·12	0·19	11	8
126			5	Sand and sandstone	8·5	0·075	0·090	0·12	0·22	14	9
125			10	Sand and sandstone	24	0·26	0·33	0·44	0·80	47	31
127	Washford Cross, Somerset (West Regional Station)	Red marls	Surface	Reddish-brown loam	23	1·5	1·7	1·8	2·3	46	32
128			1	Reddish-brown clay	20	1·5	1·7	1·8	2·5	50	33
130			2	Reddish-brown clay	18	2·6	2·8	3·1	3·6	80	45
129			3	Reddish-brown clay	21	4·7	4·9	5·5	8·0	130	85
131			5	Reddish-brown clay	19	2·8	3·1	3·3	4·2	55	40
132			10	Reddish-brown clay	15	4·3	4·5	4·5	6·1	70	55
133	Brendon Hills, Somerset	Devonian	Surface	Black fibrous loam	210	1·3	1·5	1·8	2·5	90	65
134			1	Loam and slate	9·0	0·026	0·030	0·040	0·060	12	10
135			2	Loam and slate	9·0	0·016	0·016	0·026	0·035	9·0	8·0
136			3	Loam and slate	8·0	0·0055	0·0060	0·013	0·015	7·0	6·5
137			5	Loam and slate	5·5	0·0022	0·0039	0·0085	0·016	6·0	5·5
S. 7			10	Slate	—	0·00026	0·0025	0·0092	0·046	9·5	8·0
140	Merrivale, Dartmoor, Devon	Granite	1	Gritty loam	18	0·12	0·12	0·16	0·18	22	15
141			2	Gritty loam	13	0·14	0·14	0·18	0·20	14	13
S. 1			3 to 10	Granite	—	0·00090	0·0070	0·028	0·11	12	8·5
S. 2			3 to 10	Granite	—	0·00070	0·0050	0·019	0·095	10·0	7·5
S. 3			3 to 10	Granite	—	0·00039	0·0021	0·011	0·050	9·5	7·5
S. 5			3 to 10	Granite	—	0·000015	0·00090	0·0024	0·015	7·0	6·5
139	Dousland, Dartmoor, Devon	Devonian	Surface	Loam	47	0·55	0·60	0·70	0·85	50	30
142			1	Dark brown loam	41	0·24	0·24	0·31	0·47	32	27
S. 4			Below 1	Slate	—	0·00028	0·0017	0·011	0·050	9·5	8·0
S. 6			Below 1	Granite	—	0·000030	0·00026	0·0016	0·0070	6·0	6·0

143	Moorside Edge, Yorks (North Regional Station)	Millstone grit	Surface	Fibrous loam	130	$1\cdot2\times10^8$	$1\cdot6\times10^8$	$1\cdot8\times10^8$	$3\cdot9\times10^8$	95	40
144			1	Dark grey clay	60	1·2	1·4	1·6	3·1	75	36
145			2	Dark grey clay	35	0·70	0·95	1·0	2·4	85	33
146			3	Dark grey clay	39	1·1	1·5	1·6	3·1	75	36
147			5	Dark grey clay	19	0·85	1·0	1·2	2·9	70	31
148			10	Yellow and grey clay	15	0·31	0·33	0·37	0·75	28	16
149	Westerglen, Falkirk (Scottish Regional Station)	Boulder clay	Surface	Fibrous loam	38	0·55	0·65	0·75	1·1	50	20
150			1	Fibrous loam	30	1·0	1·0	1·1	1·5	60	20
151			2	Clay and loam	19	1·1	1·1	1·2	1·7	60	21
152			3	Dark grit and clay	18	0·60	0·70	0·80	1·2	50	19
153			5	Dark grit and clay	18	1·9	2·2	2·5	3·3	75	22
154			10	Dark grit and clay	15	2·1	2·3	2·6	3·2	80	24
160	Teddington, Middlesex (N.P.L.)	London clay	Surface	Fibrous loam	26	1·0	1·1	1·2	1·7	40	14
161			1	Sandy loam	20	0·65	0·70	0·90	1·1	22	14
162			2	Sandy loam	13	0·60	0·65	0·65	1·0	20	12
163			3	Fine gravel	6·5	0·50	0·60	0·65	0·85	20	10
164			5	Coarse gravel	2·9	0·17	0·18	0·21	0·30	12	6·5
166			7	Fine sand	2·6	0·14	0·14	0·15	0·21	7·5	5·0
165			10	Sand and shingle	20	1·2	1·4	1·5	1·8	31	16
167	Wychbold, Droitwich (Midland Regional Station)	Red marls	1	Red clay and loam	15	1·5	1·8	2·0	3·3	49	22
168			2	Red clay	13	3·1	2·9	3·0	4·7	42	23
169			3	Red clay	14	2·1	2·2	2·4	4·0	60	29
170			5	Red clay and stones	15	3·9	4·6	4·8	8·5	55	31
171			10	Red clay and stones	21	3·7	4·0	4·2	7·0	60	30
172			20	Red clay suspension	31	6·0	7·0	7·5	11·0	65	16
173			30	Red clay suspension	41	6·0	7·0	7·0	12·0	65	38
174			40	Red clay suspension	25	5·5	6·5	6·5	10·0	60	13
175			50	Red clay	27	7·0	7·5	8·5	12·0	60	16
176			100	Grey clay and salt	28	16·0	21·0	22·0	25·0	—*	—
177			150	Red clay and salt	27	—	←——— about 100 ———→			—*	—
178			200	Red clay and salt	24	—	←——— about 100 ———→			—*	—
179			250	Red clay and salt	22	2·2	2·3	2·4	2·4	30	13
180			300	Red clay and salt	21	7·0	8·0	8·5	17·0	95	24

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* The values of the dielectric constant for samples Nos. 176, 177, and 178, were difficult to measure accurately owing to the high conductivity of these samples. Sufficient measurements were made, however, to indicate that the dielectric constant was negligible compared with the conductivity; that is, $\kappa f/(2\sigma) << 1$.

conductivity (i.e. above 10^8), the loam and chalk an average value in the neighbourhood of 10^8, and soil of a sandy or gritty nature an appreciably lower conductivity. The conductivity of the surface layer is to some extent influenced by its moisture content, which in turn is very dependent upon the nature of the subsoil. The values obtained on the samples from the deep bore at Droitwich are interesting as showing that the conductivity rises progressively as the depth is increased, attaining a maximum value at 150 and 200 ft. of about 10^{10}, which is comparable with the value for sea water. At the depths of 150 and 200 ft. only the order of the conductivity was obtained, as the condensers used were not suitable for such high values. It was not considered worth while, however, to construct special containers in order to obtain more accurate values for samples from these depths. These high values are most probably due to the slight content of salt which was observed in the samples obtained from these depths. At the greater depths of 250 and 300 ft. the conductivity decreased to about one-tenth of the above maximum value.

The results obtained at Teddington are also of some interest, as showing the presence of a poorly-conducting streak of moderately dry gravel and sand, with moist sand below having from 6 to 10 times the conductivity of the layers immediately above.

(c) *Values of Dielectric Constant.*

With regard to the results for the dielectric constant recorded in Table 2, it is to be noted that the values of this quantity always decrease as the frequency is raised. In some, but not all, cases the values appear to be increased by the presence of an abnormal amount of moisture. On the whole the values of the dielectric constant are higher for the clays than for the sandy and gritty materials, while the solids give relatively low values, as would be expected from the results of previous investigators. It will be appreciated from all the results obtained that in few cases, and only at the highest frequencies, is the actual value of the dielectric constant of great importance in the study of radio-wave propagation conditions. Where it is of importance the values here obtained are considered to be of sufficient accuracy to be used for calculation.

(d) *Conclusions from Electrical Survey.*

Within certain limitations this electrical survey may be employed to predict at least the order of the properties of the ground for any site at which the nature of the surface soil and the geological classification are known. The ordinary geological map can, so to speak, be designated in areas of different conductivities. Alternatively, the experience gained in this investigation indicates that a survey of any area of ground can be carried out fairly rapidly, by selecting a few samples of the soil and measuring its constants in the laboratory. For a preliminary survey these measurements could be conducted at audio frequency, with standard equipment for measuring the capacitance and resistance of condensers. A more detailed survey of the selected site could then be carried out at the frequency which is of immediate interest. This procedure has considerable advantages in convenience and rapidity over any field method involving measurements of the tilt of the wave-front or of the attenuation of the field strength with distance. The advantage possessed by these latter methods, however, is that they automatically integrate the contributions to the field at the surface of the currents induced in the soil at different depths. The penetration of the currents in soils of different conductivities is duscussed to some extent in the following section, but the general consideration of this aspect of the problem must remain for future investigation.

(6) PENETRATION OF ELECTRIC WAVES INTO THE GROUND.

From a knowledge of the electrical properties of the ground it is now possible to calculate the rate of attenuation of the current flowing at any depth as a result of an electrical disturbance produced at the surface. If the amplitude of the current flowing at the surface be I_0 at a frequency corresponding to the wavelength λ, then the amplitude of the current flowing at a depth x is I_x, where

$$I_x/I_0 = e^{-(2\pi x/\lambda)\alpha}$$

and
$$\alpha^2 = \frac{\sigma}{f}\sqrt{\left(\frac{\kappa^2 f^2}{4\sigma^2} + 1\right)} - \frac{\kappa}{2}$$

In cases where $\kappa f/(2\sigma) << 1$, the formula for α

reduces to
$$\alpha = \sqrt{\left(\frac{\sigma}{f} - \frac{\kappa}{2}\right)}$$

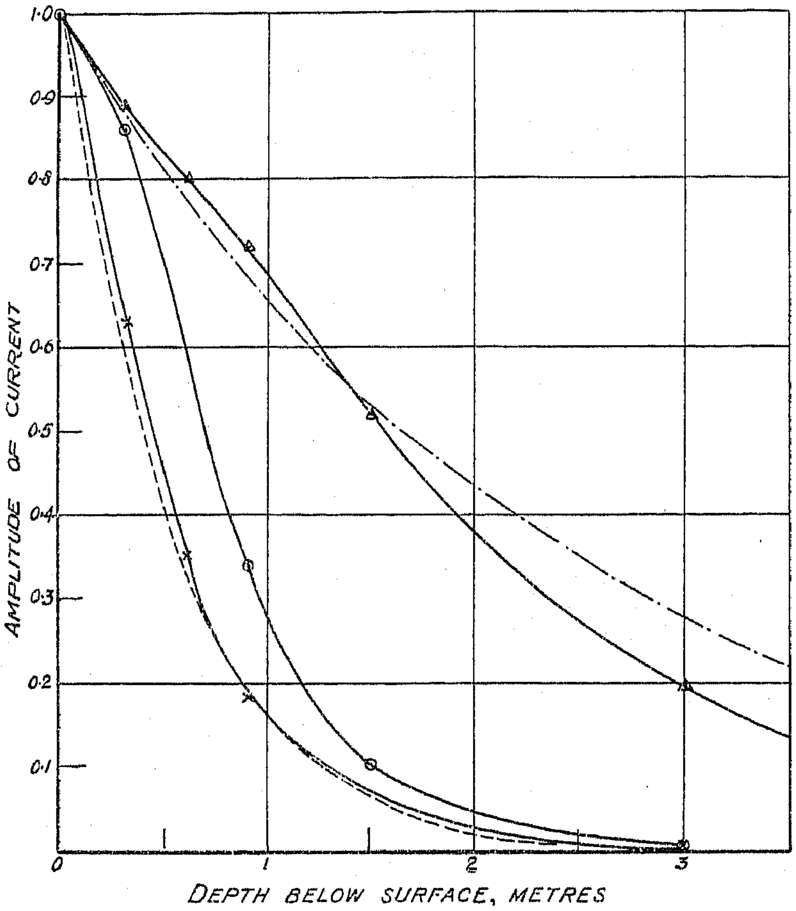

FIG. 6.—Relation between current amplitude and depth below surface for a frequency of 10 000 kilocycles per sec.

—×— Rugby site (1)
—⊙— Rugby site (2)
—△— Baldock
} calculated from measurements in Table 2.

— — — Curve calculated for $\sigma = 10^8$, $\kappa = 20$.
-·-·-·- Curve calculated for $\sigma = 10^9$, $\kappa = 50$.

With the aid of this formula, graphs showing the relation between current and depth were calculated for a few typical cases from the measured data given in Table 2. In these calculations the average conductivity and dielectric constant were used for each layer of soil for which measurements were available.

The first set of such graphs is presented in Fig. 6, which shows the calculated results for the two sites at Rugby and for Baldock at a frequency of 10 000 kilocycles per sec. From these curves it is seen that at Rugby, over 90 per cent of the current is carried in the first 1·5 metres (5 ft.) of soil, while at Baldock a little less than half the current flows in this depth of soil; an extrapolation of the results shows that a depth of about 4 metres (13 ft.) is required to carry 90 per cent of the current. The same diagram contains curves calculated for two hypothetical soils having uniform conductivity and dielectric constant at different depths. A comparison of these curves with those obtained from the actual measurements shows the accuracy to which, for practical communication purposes, the soils at the two stations may be assumed to have uniform values of 10×10^8 and 50 for Rugby, and 10^8 and 20 for Baldock, for the conductivity and dielectric constant respectively.

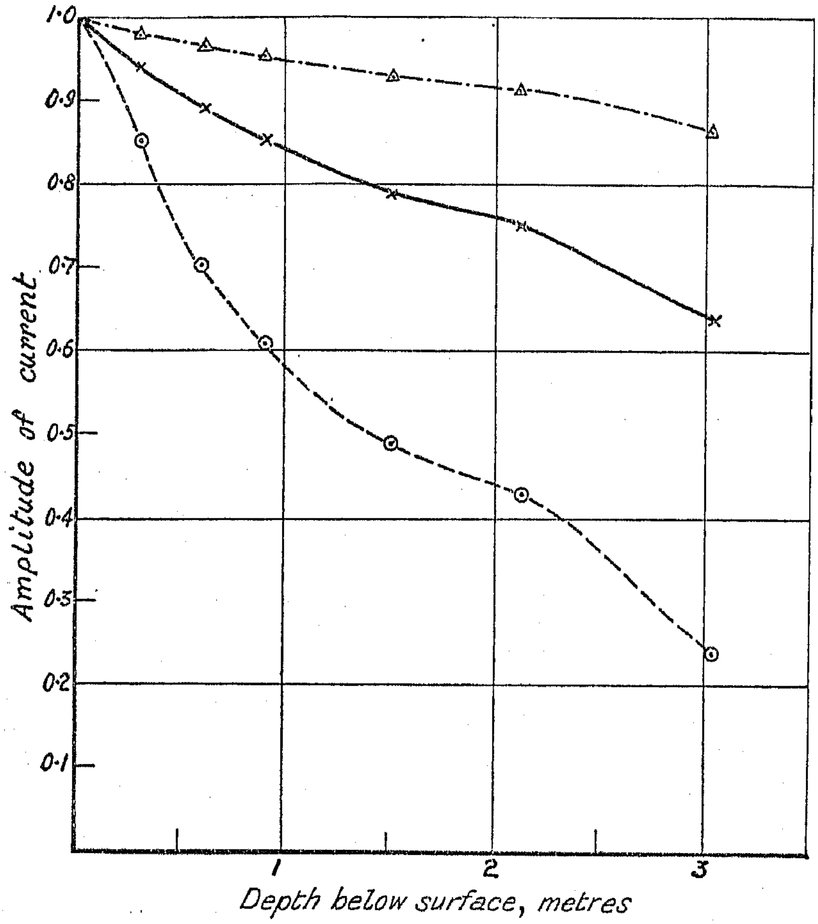

FIG. 7.—Relation between current amplitude and depth below surface, calculated from measurements on soil at N.P.L. (Site No. I).

-·-△-·- Frequency 100 kilocycles per sec.
—×— Frequency 1 000 kilocycles per sec.
---⊙--- Frequency 10 000 kilocycles per sec.

The variation of the penetration of the current with frequency is illustrated in Fig. 7, which shows the curves calculated from the measurements on soil from site I at the N.P.L., Teddington, for the three frequencies of 100, 1 000, and 10 000 kilocycles per sec. At the lowest frequency about 86 per cent of the current is flowing at a depth of 3 metres, while at the highest frequency the value is reduced to about 25 per cent. The inflection of the curves at a point corresponding to a depth of about 2 metres is due to the marked decrease in the conductivity of the soil at this site at this depth (5 to 7 ft.). At the lower depth of 3·03 metres the conductivity rises to a value which is actually higher than that at the surface.

With the aid of the results of measurements on samples from Droitwich at greater depths, the graphs in Fig. 8 were calculated. These show the decay in current amplitude with depth down to 18 metres (about 55 ft.) for the two frequencies of 100 and 1 000 kilocycles per sec. Even at the lower frequency the amount of current which flows at depths of more than 30 metres (over 100 ft.) is negligible.

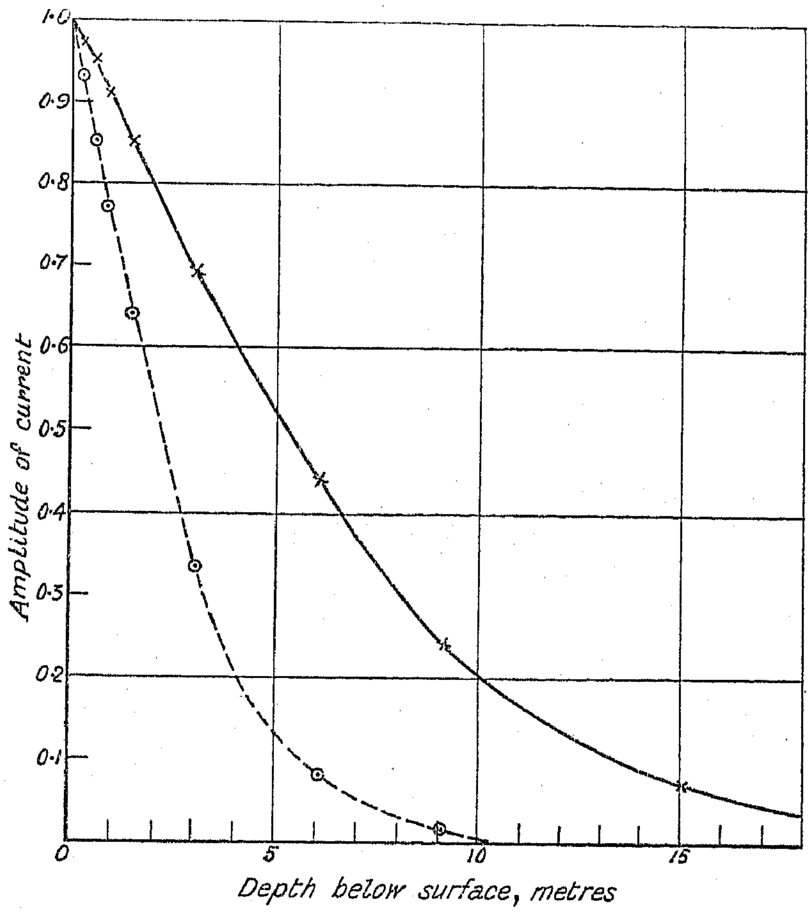

FIG. 8.—Relation between current amplitude and depth below surface, calculated from measurements on soil from Droitwich.

—×— Frequency 100 kilocycles per sec.
---⊙--- Frequency 1 000 kilocycles per sec.

While the graphs shown in Figs. 6, 7, and 8, give some idea of the depth to which currents at various frequencies penetrate in typical soils, it must not be assumed that these indicate the depth of soil which must be taken into account in studying the propagation of electric waves along the surface of the earth. The field at the surface will be determined by the resultant of the field of the arriving waves and of the secondary field due to the currents flowing in the soil. The effective contribution of the latter will naturally decrease rapidly with their depth below the surface, to an extent which must remain for further investigation.

(7) ACKNOWLEDGMENTS.

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DISCUSSION ON

"THE HEATING OF DOMESTIC PENDANT LAMP FITTINGS AND THEIR CONNECTING LEADS."*

North Midland Centre, at Leeds, 6th February, 1934.

Mr. J. C. Craven: The authors mention that they have tested lamps with ratings up to 200 watts, but in my experience it is only on very rare occasions that lamps rated at more than 100 watts are used in domestic work. Is there any significance in the order in which the four methods of mitigating the heating of the pendant fittings and flexibles are given on page 545? Does it represent the order in which the authors think the subject can best be tackled? Although the root of the trouble—the heat—is to be found in the lamp, this is put last. The interesting method shown in Fig. 8 of reducing the temperature-rise of the lamp cap and lampholder will clearly increase the cost of the lamp, whereas the general public consider that the price of lamps is already much too high compared with that of other domestic electrical accessories. I should like to mention some of the faults on pendant flexibles which have occurred in my house, which I have occupied for 20 years. The first fault occurred after a period of about 8 years, and had nothing to do with heating. It arose on a dining-room 3-light fitting with a counterweight: the strands of the flexible conductors broke one by one and eventually there was an open circuit. After 10 years a fault occurred in the scullery, in which washing is done. The flexible short-circuited at the lampholder and blew the fuse, but the pendant did not break. After a period of about 12 years a short-circuit developed immediately above the lampholder in the kitchen. The lamp and shade fell to the floor and both were broken. The more serious troubles in connection with flexibles occur where push-bar or key-switch lampholders are used. Failure is accelerated by the combined effect of the heat adjacent to the lampholder and of the repeated bending of the flexible when the lamp is switched on and off. The flexible cords manufactured by the Cable Makers Association leave very little to be desired; but those of Continental manufacture have very little mechanical strength, and very little rubber on them.

Mr. W. Fordham Cooper: Now that the authors have determined the exact nature of the deterioration caused by heat, and suggested a number of methods of minimizing the trouble, it is for the manufacturers to produce improved equipment. It appears to me that the copper disc on the pendant lampholder would be quite a reasonable addition to lighting fittings used in industrial installations. A few days ago I examined some fittings in my own house which had been used in conjunction with 100-watt lamps for about 2 years, and found that they had all started to deteriorate. With regard to "the risk of short-circuit or burning of the flexible cord occurring adjacent to or within the holder," and "the further possibility of metallic holders becoming alive," mentioned in the Summary, I find as a result of my own experimental work and of accident investigation that there is an appreciable fire risk with direct currents, but this risk is very much smaller where alternating currents are used. In fact, I have had very great difficulty in making a piece of short-circuited flexible catch fire with an alternating current. On the other hand the risk of fatal electric shock from flexible with perished insulation, particularly with pendants within reach of a conducting floor such as is found in bathrooms, sculleries, and wash-houses, is considerable in the case of alternating current; whereas 200-volt direct-current shocks are not generally fatal. So far as the fire risk is concerned the authors state that the point of maximum danger is ⅝ in. from the terminal, and I take it that this will be inside the cord grip. The cord grip is a most important part of a lampholder or portable appliance, and is frequently the worst from a design point of view. Shock accidents with lampholders are frequently due to defective cord grips; the same is true in the case of fires, particularly where switch lampholders, or any other lampholders which are frequently handled, are employed. The use of bakelite lampholders is rapidly extending, and this will undoubtedly greatly reduce the number of cases of electric shock from the lampholder itself, but it must be admitted that until very recently the design of bakelite-lampholder cord-grips was very inferior. Such cord-grips are frequently very harsh and tend to cut through the insulation, particularly when it has been damaged by overheating. Very few cord grips are properly designed to take a circular braided or circular rubber flexible, and the absence of an effective cord grip has been the indirect cause of a good many burned hands and at least one or two fires. Recently bakelite lampholders with cord grips made with a rubber ring compressed in a sort of stuffing gland have been produced, and these seem an improvement, particularly when used with circular flexible or cab-tyre-sheathed cable, but the disclosures made in the paper lead me to suspect that the rubber ring will quickly deteriorate. There seems no reason, however, why this should not be replaced by a ring made of some other material which is not so subject to damage by heat. As a result of a fire in a lace factory, which started at the cord grip of a lampholder, I looked into the question of making some improvement which would remove the bending stress on the conductor at this point. One suggestion is a rubber sheath with a beaded rim held in a gland. This affords considerable mechanical protection, but is perhaps liable to damage by overheating. It should be possible, however, to substitute some other substances for rubber. This design has the advantage that the part of the insulation most liable to damage by heating is protected from contact with the hands. Another defect of many existing bakelite lampholders is that the shade ring, the top of the lampholder, and the cord grip, are not independent. The result is that every time the shade is touched the cord grip is either loosened or squeezed up too tight, thus damaging the flexible. This has been the cause of a great deal of trouble. The next point I wish to refer to is the distinction between heat-resisting and flameproof flexibles. It has been stated that cable makers can now produce a type of insulation with a slightly higher permissible temperature, and with this few degrees' allowance it is, I gather, now possible to design fittings and holders which will be satisfactory. There will still, however, remain the chance of a fire being started through damage at the cord grip, even though the cable has not been affected by the heat. A heat-resisting cable is not necessarily a non-inflammable cable, and a non-inflammable cable is not necessarily a heat-resisting cable. By heat-resisting I mean a cable that would withstand a working temperature substantially above the present limits; such a cable might easily propagate a fire when once it had been started. On the other hand, a cable with quite a low temperature rating might be overheated at the working temperature but yet not support combustion. I have found that some of the most inflammable cable (once the fire has been started) is the heat-resisting type frequently sold for use with electric irons. Here the hemp packing and braid burn very readily. These points have been dealt with by the Textiles Co-ordination Research Committee.* The most practicable flexible from the point of view of fire risk which I have yet met is the tough-rubber-sheathed type. Providing it has not been seriously heated by an excessive overload, which can be prevented by fuses, it is very difficult to set this on fire. In conclusion, I would sum up the position as follows. The authors have thoroughly investigated the difficulties which arise from the overheating of the fitting and the lampholder, but their work will remain incomplete until the design of cord grips has been thoroughly investigated, and I suggest that there is scope for some very useful research here. Further, even when the rise of temperature has been reduced to a minimum by the re-design of fittings, etc., it is not sufficient to produce a cable with good heat-resisting properties; it should also be non-inflammable. I suggest the following specification as giving the requirements of a good fireproof flexible for general service: (1) Where there is a danger of very heavy currents, continuous overloads, or other sources of high temperature, rubber must be eliminated, since, if present, it will decompose and impregnate the fireproof braiding, rendering it inflammable. (2) The insulating medium should be waterproof. (3) The cable must be flexible and not easily damaged by kinking and repeated bending. These last two requirements are the chief difficulties in connection with asbestos. It needs a waterproof insulating sheath to the conductors, and it has a very short and brittle fibre which causes the cable to disintegrate in use. (4) The "fire proof" qualities must not be destroyed by immersion in water, oil, petrol, etc., if the cable is to be of general utility; i.e. the fire-proofing ingredient must not be dissolved out by these liquids. It is obvious that the cable cannot be fireproof until petrol has dried off.

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* Paper by Messrs. P. D. Morgan, H. G. Taylor, and W. Lethersich (see vol. 73, p. 545).

Mr. H. Moss: I should like to ask whether the authors have carried out any tests with shades of other than the conical type. It would be interesting to know whether the new type of ventilating shade made by the Benjamin Electric Co. has any advantageous effect in decreasing the temperature-rise round the lower end of the cord. I gather that the critical point is within $\frac{5}{8}$ in. of the lampholder terminal. I should therefore like to call attention to the fact that there is on the market a lampholder with an ebonite screw plug which separates the two strands of the flexible cord by $\frac{1}{4}$ in. where they leave the holder. As the strands do not come in contact until a point some $\frac{3}{4}$ in. away from the lampholder is reached, this type of lampholder should be fairly safe. With reference to conical shades and domestic lighting, to every 1 or 2 conical shades on a domestic installation there are usually 10 or 12 fancy shades. Do similar effects to those noticed in connection with conical shades occur with shades of the bell-shaped or fancy-glass type? It would be interesting to know whether the authors have carried out experiments with other metals than copper, e.g. iron and aluminium.

Mr. R. M. Longman: I recently came across some pendant fittings in which a disc of approximately 3 in. diameter was incorporated in the base, and as these had been made some years previously the presence of the discs was not due to the authors' investigations. I would emphasize the desirability of using 3-light fittings, since these give much lower temperature-rises than single 100-watt lamps. Moulded lampholders have much in their favour, but in these the cylindrical part with the bayonet socket should be reinforced. Ventilated fittings do not appear to reduce the heating effect appreciably, and a reliable bayonet-type lampholder for 100- and 150-watt lamps is most desirable.

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* Second Report of Textiles Co-ordination Research Committee (H.M. Stationery Office).

Mr. J. Hearn: During the course of their experiments the authors used a lamp with a moulded bakelite cap. I should be glad to know what kind of cement was used for fixing this to the glass, as I do not think the cap would be able to stand the temperatures employed in production at present. In modern methods of lamp manufacture several very hot gas flames play on the cap holder, which, even though it is guarded by means of a metal shield, would be liable to be damaged. Again, if a low-temperature cement is used, would it stand up to the standard test which it is required to pass (a torque of about 1 lb. ft., I believe) when the cap is twisted against the glass bulb?

Mr. J. N. Waite: The research work carried out by the authors has been extremely opportune, because the tendency is for supply tariffs to go down and therefore for lighting consumption to increase. This means that a greater amount of heat has to be dissipated by the fittings. Fitting designers can obviously introduce many improvements which will have the effect of mitigating this danger.

Messrs. H. G. Taylor and **W. Lethersich** (*in reply*):* Since the paper was read at Leeds a 12 in. length of flexible cord has come into our hands in which a short-circuit had occurred just above the lampholder owing to deterioration of the insulation. About ½ in. of insulation on each wire has disappeared, and the fuses blew when the short-circuit took place. The flexible cord had been in use in a kitchen for 15 years with a 60-watt lamp. It has deteriorated throughout its whole length and is so stiff that, when supported as a beam 10 in. long, the deflection produced by a load of ¼ lb. in the centre is only ½ in. and there is no permanent set on removal of the load.

In reply to Mr. Craven, we tested lamps up to 200 watts because we wished to cover the whole field of domestic lighting and also to envisage future developments, although we agree that 200-watt lamps are not often used in domestic installations to-day. The root of the problem of flexible-cord deterioration is undoubtedly in the lamp, but that does not absolve one from considering solutions which do not affect the lamp; there is, however, no significance in the order of arranging the methods of mitigating the effects of temperature-rise given on page 545 (vol. 73).

We appreciate Mr. Fordham Cooper's contribution to the discussion, and his suggestions with respect to the need for improvement in the design of cord grips. We regard this as a piece of work which should be undertaken by manufacturers rather than by the E.R.A., since it would not be possible to design one particular type of cord grip which could be applied to the many existing designs of lampholders.

Mr. Moss inquires about the temperature-rise of the new type of ventilating shade made by the Benjamin Electric Co. The type referred to is probably the "Coolicon," but this has been replaced by a very much improved design, known as the "Saaflux," which does not depend on ventilation for its low temperature-rise. We understand that this fitting has been certified by the N.P.L. as giving to the leads a temperature-rise of not more than 50 deg. C. We have not actually tested any bell-type decorative shades, but anticipate that they would give the same temperature-rise as the plain conical shade. Other metals are only slightly inferior to copper for use as discs on lamp fittings.

In reply to Mr. Hearn, we fixed the ebonite caps to the lamps by means of either plaster of Paris or litharge and glycerine cement. We admit that this method is only suitable for an experimental investigation. We understand that lamp caps are usually fixed with a synthetic resin cement. The question of fixing does not present an insuperable difficulty to the use of non-metallic caps.

Mr. Waite points to the increasing seriousness of the flexible-cord deterioration problem which may be expected with reduction in supply tariffs. Although the problem has been outstanding for many years we hope that in now tackling it the E.R.A. has given a lead which will be rapidly followed by the manufacturers, in order that the increasing use of electric light which will follow the reduction in tariffs may not be accompanied by an increase in the number of accidents—a result which would react unfavourably on the whole industry.

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* Mr. P. D. MORGAN, one of the authors of the paper, died on the 16th February, 1934.

THE EMISSION OF SPECIAL RADIO SIGNALS FOR THE STUDY OF THE IONOSPHERE.[*]

By H. A. THOMAS, M.Sc., Associate Member.

[From the National Physical Laboratory.]

(*Paper first received* 12*th September, and in final form* 18*th December*, 1933.)

SUMMARY.

The paper gives an account of the development and construction of the new transmitter now installed at the National Physical Laboratory for the emission of the special signals required in connection with modern research on the ionosphere. It also deals briefly with the methods adopted for the dissemination of standard-frequency signals for calibration purposes.

The new installation has been designed to handle all the sending services required from the Laboratory over a continuous frequency range of 250 to 6 000 kilocycles per sec. (wavelength 1 200 to 50 metres). Owing to the rapid change in the emitted frequency required in many tests, a single oscillating circuit is employed and the oscillations are maintained by a push-pull system. A series modulator is provided for controlling the anode-circuit supply to the oscillator. The special emissions required for ionospheric research consist of frequency-change and pulse transmissions. In the former emission, the frequency is continuously varied over a small range by means of an entirely automatic mechanism which gives precision of both timing and frequency-change, while in the latter type of emission, pulses of waves may be emitted of short duration and at a repetition frequency synchronized with the a.c. supply mains.

Two types of standard-frequency programmes are emitted. In one of these the output from the continuously-running 1 000-cycle standard tuning-fork is used to modulate a suitable carrier wave; and in the other a standard radio frequency is emitted by using the transmitter as the final stage in an amplifier supplied by a quartz-crystal-controlled master oscillator.

All the operations required in connection with these various emissions are effected by simple panel switchgear so as to render rapid changes in frequency and type of transmission possible, while a cathode-ray oscillograph equipment is incorporated for the observation of the modulation envelope.

The whole installation was designed and constructed at the Laboratory for an input power of at least 4 kW, although at present the input is limited by supply conditions to 2 kW.

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(1) INTRODUCTION.

The experimental study of the properties of the ionosphere has involved the development of a new technique at both the emitting station and the receiving station. In 1925, E. V. Appleton and M. A. F. Barnett[†] described the first experiments utilizing the frequency-change method for the determination of the height of the Kennelly–Heaviside layer. This method consists in producing a small continuous change in the frequency of the emitted radiation while a continuous record is made of the field intensity at the receiving station. By counting the number of interference fringes obtained by this known frequency-change, the relative strengths of the direct and indirect waves can be obtained together with the height of the layer.

Since 1926, a transmitter installed at the National Physical Laboratory has been used for the production of these special signals, the frequency-change being effected by manual control. The results of the first experiments carried out with this transmitter were published by Appleton and Barnett in 1926.[‡] In 1931 the more stringent demands made upon this frequency-change apparatus necessitated the introduction of an automatic mechanism to give the required precision.

In that year it was decided to carry out experiments with the pulse retardation method, which had previously been used in America to a limited extent.[§] In this method, a small pulse of waves of short duration is emitted at regular intervals, and at the receiving station the ground-wave pulse, together with successive pulses and echoes, is made visible by means of a cathode-ray oscillograph equipment. Various simple electrical pulse-emitters were used in the original experiments, but, with the introduction of photographic recording at the receiver, the necessity for exact synchronization between the emitted pulse-frequency and the cathode-ray oscillograph time-base demanded an improved emitting apparatus. Accordingly an electromechanical pulse emitter was developed, and this is incorporated in the new equipment.

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[*] The Papers Committee invite, written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

[†] "Local Reflection of Wireless Waves from the Upper Atmosphere," *Nature*, 1925, vol. 115, p. 333.

[‡] "On Wireless Interference Phenomena Between Ground Waves and Waves Deviated by the Upper Atmosphere," *Proceedings of the Royal Society*, A, 1926, vol. 113, p. 450.

[§] G. BREIT, M. A. TUVE, and O. DAHL: "Effective Heights of the Kennelly–Heaviside Layer in December, 1927, and January, 1928," *Proceedings of the Institute of Radio Engineers*, 1928, vol. 16, p. 1236.

The object of the present paper is to describe the improved methods of generating frequency-change and pulse signals, together with the general arrangement of the new installation.

(2) General Description of Transmitter.

(a) *Outline of Requirements.*

The transmitter was required for certain services besides the emission of special signals for ionospheric research, and consequently, in designing the new installation, the following six types of transmissions had to be provided for: (i) Continuous waves (C.W.). (ii) Frequency-change C.W., consisting of a small periodic change in the nominal frequency, according to a prearranged code. (iii) Pulse, consisting of a series of short pulses of about 1/10 000th sec. duration at a repetition frequency of 25, 50, or 100 per sec. (iv) Modulated C.W., the modulation being derived from a standard 1 000-cycle fork. (v) Standard-frequency C.W., the installation being used as a power amplifier supplied by a standard-frequency source. (vi) Telephony.

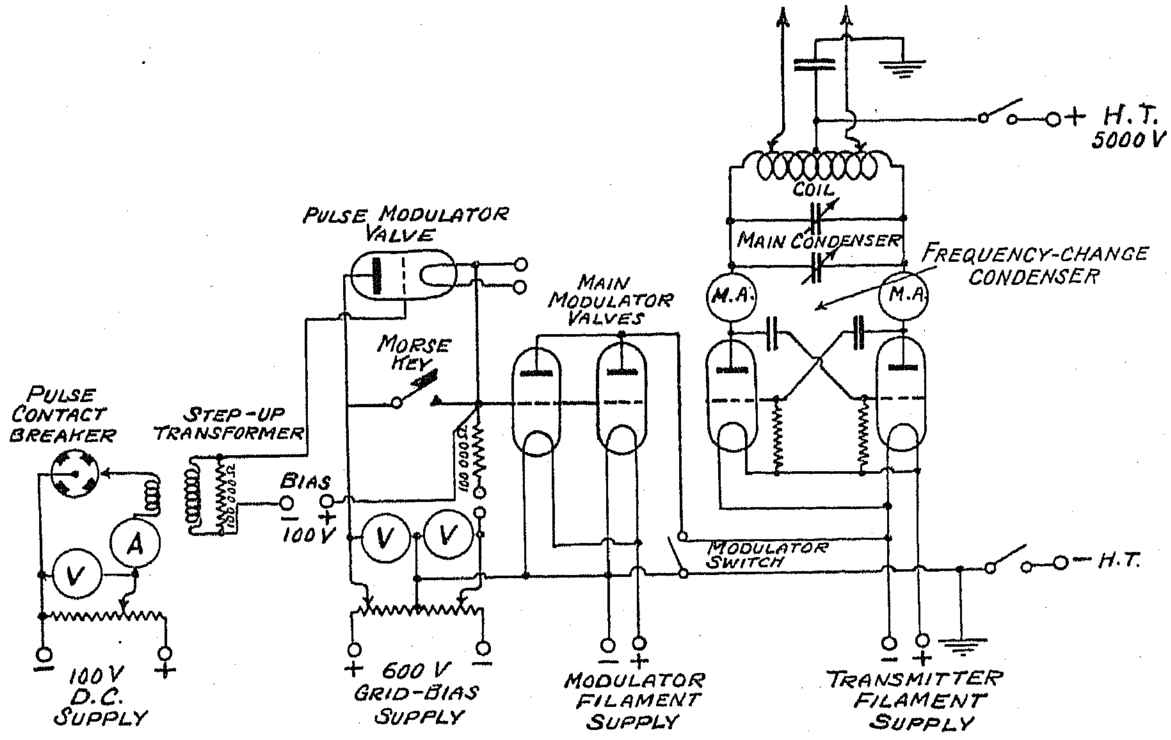

Fig. 1.—Schematic circuit diagram.

It was considered desirable to make the control of the set simple, and the electrical operation as accurate and reliable as possible, while retaining to the utmost that flexibility which is so essential in a piece of apparatus to be employed for experimental research.

The frequency range for any of these types of transmissions was specified as 250 to 6 000 kilocycles per sec. (wavelengths 1 200 to 50 metres), and it was essential to ensure that both the frequency of the propagated wave and the type of transmission could be changed with great rapidity. Further requirements were that the apparatus should be capable of being controlled by comparatively unskilled operators and that the calibrations should have a reasonably high degree of permanence. The available source of high-tension voltage was a 5 000-volt d.c. motor-generator set together with a similar spare set, and consequently the transmitter was arranged for use at this voltage in the first place, but, in view of the possibility of a later demand for increased power, the essential portions of the installation were designed for 10 000 volts, since this H.T. supply would be necessary to give a greater power output.

(b) *Schematic Arrangement of Apparatus.*

It was decided to use a conventional push-pull single tuned circuit for the main oscillator system, since the requirements involving ease of operation and rapidity of change of emitted frequency prevented the use of any coupled-circuit arrangements. The aerial and earth or counterpoise connections are made by adjustable tappings on the main tuning coil, and a dipole aerial system can be used for certain tests. To cover the large frequency range required, it was decided to use three tuning coils and to make these rapidly interchangeable by means of switchgear.

The frequency-change transmissions were effected on the original experimental transmitter by manual variation of a small condenser connected in parallel with the main tuning condenser, and, since this method was found to be satisfactory, it was decided to adopt a similar electrical method in the new design. Automatic control of this condenser was desirable to improve the accuracy of the frequency-change and also to eliminate the considerable fatigue involved in a long hand-operated transmission.

The main factor which governs the circuit arrangement is the method adopted to produce the pulse emissions, and after various possible methods had been considered it was decided to adopt a mechanical contactor to generate the pulses applied to the grid of a series modulator valve. This series type of modulation was equally suitable for the other types of transmissions, but necessitated an insulated filament supply to the transmitting valves.

The type of modulation having been decided upon, the question of the most suitable type of circuit was considered. The schematic arrangement finally adopted is shown in Fig. 1. For frequency-change transmissions, the automatic mechanism operates a condenser connected in parallel with the main tuning condenser. For pulse transmissions, the grid bias to the modulator valve is set to give no output from the transmitter, and a pulse signal is inserted in the grid circuit of the modulator, thereby raising the grid potential momentarily and producing an oscillation for a period of about 0·1 millisecond. The details of this pulse generator are described later. For normal modulation of the transmitter for the emission of the standard 1 000-cycle fork signal, the grid bias to the modulator is adjusted to give about half the H.T. voltage across the transmitting valves, and the modulating e.m.f. is inserted in series with the modulator grid circuit by means of a plug. If telephony modulation is required, the amplified speech voltage is inserted at the same point. By means of switches, the modulator can be short-circuited, the coupling condensers between the anodes and grids of the transmitting valves disconnected, and the two grids connected to external terminals. In this manner the self-oscillating system is converted into a simple push-pull amplifier for passing to the aerial the output of a radio-frequency amplifier supplied from a quartz-controlled master oscillator for the emission of standard-frequency waves.

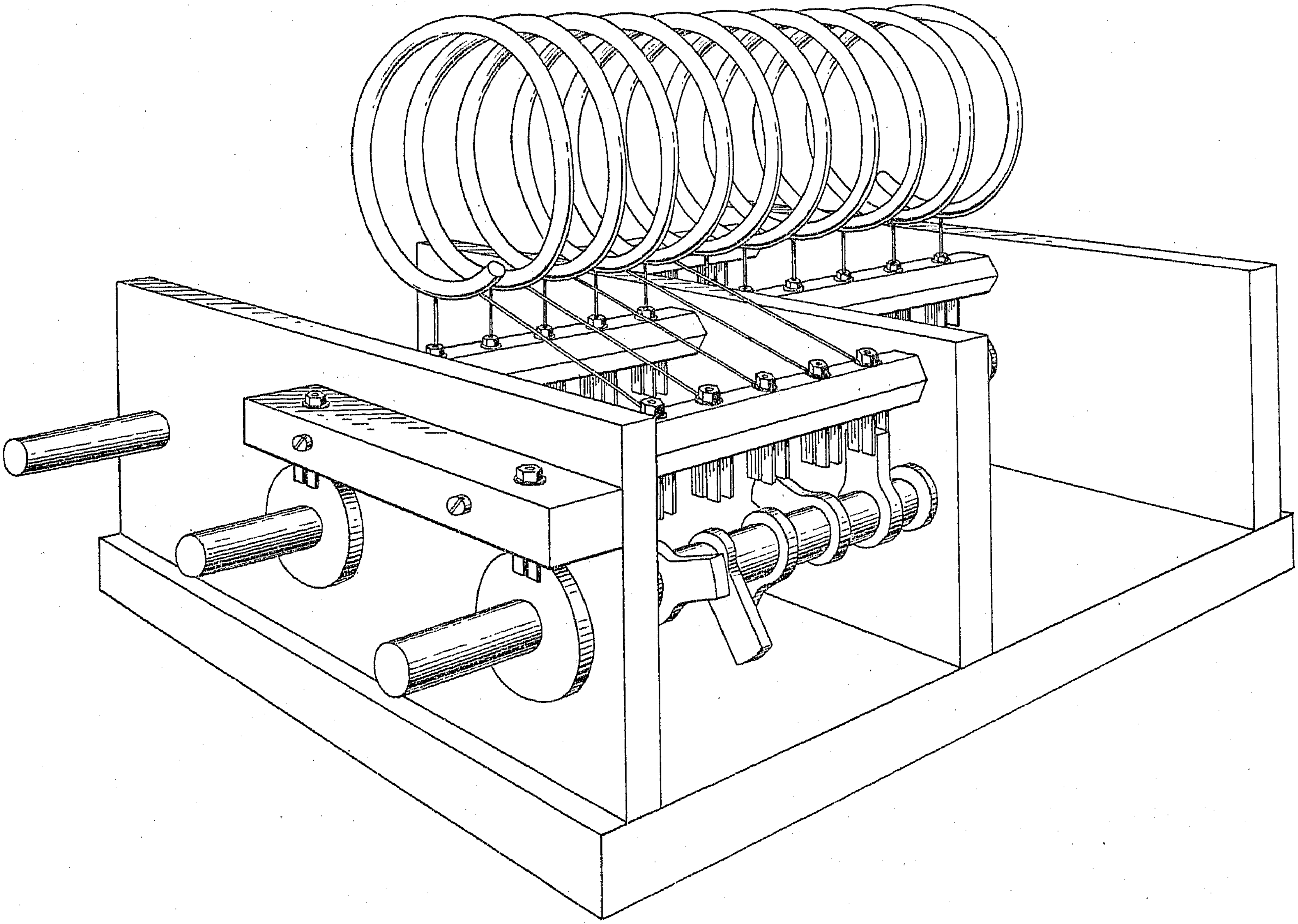

FIG. 2.—Short-wave coil.

(3) DESIGN OF TRANSMITTER.

(a) The Oscillatory Circuit.

In the design of the oscillation system, attention was primarily devoted to obtaining efficiency at the highest frequencies of the order of 6 000 kilocycles per sec., since it is at these frequencies that serious losses may occur if great care is not taken with the arrangement of the component apparatus. It is probable that some inefficiency will exist if the lay-out of the coils and condenser has to conform to a rack mounting with panel controls, and the difficulty lies in arranging the various components so that the leads are short and well spaced, while at the same time the spacing of the components is sufficient to reduce mutual interaction.

It was decided to dispense with coil formers for the two smaller coils, and to construct these of $\frac{1}{4}$ in. diameter copper rod. The general construction of the smallest coil is shown in Fig. 2. The coil itself is made of 10 turns of copper rod, the coil diameter being $3\frac{1}{2}$ in. and the turn spacing $\frac{3}{4}$ in. The inductance of this coil is about 5 μH. Tapping connections of No. 14 S.W.G. hard-drawn brass wire are hard-soldered to each turn as shown, and are taken to the contacts supported on mycalex hexagonal rods below the coil. These tapping connections also act as a rigid support for the coil itself. The four sets of hexagonal mycalex rods together with their five contacts are supported by three cheeks of keramot, which are mounted on a glass base $\frac{3}{4}$ in. thick. These cheeks hold the bearings for the four tapping shafts with their five arms; as each arm is spaced 72° from its neighbour, rotation of the tapping shaft makes contact successively to the five tapping points. The contact from these shafts is made by means of a disc and rubbing contact to four terminals mounted on the outside of the keramot cheeks. It has been found that these contacts can carry 50 amperes without overheating, and the insulation is ample for 10 000 volts at radio frequency between the two anode tapping points. The action of changing the tapping is rapid and readily controlled by a panel knob.

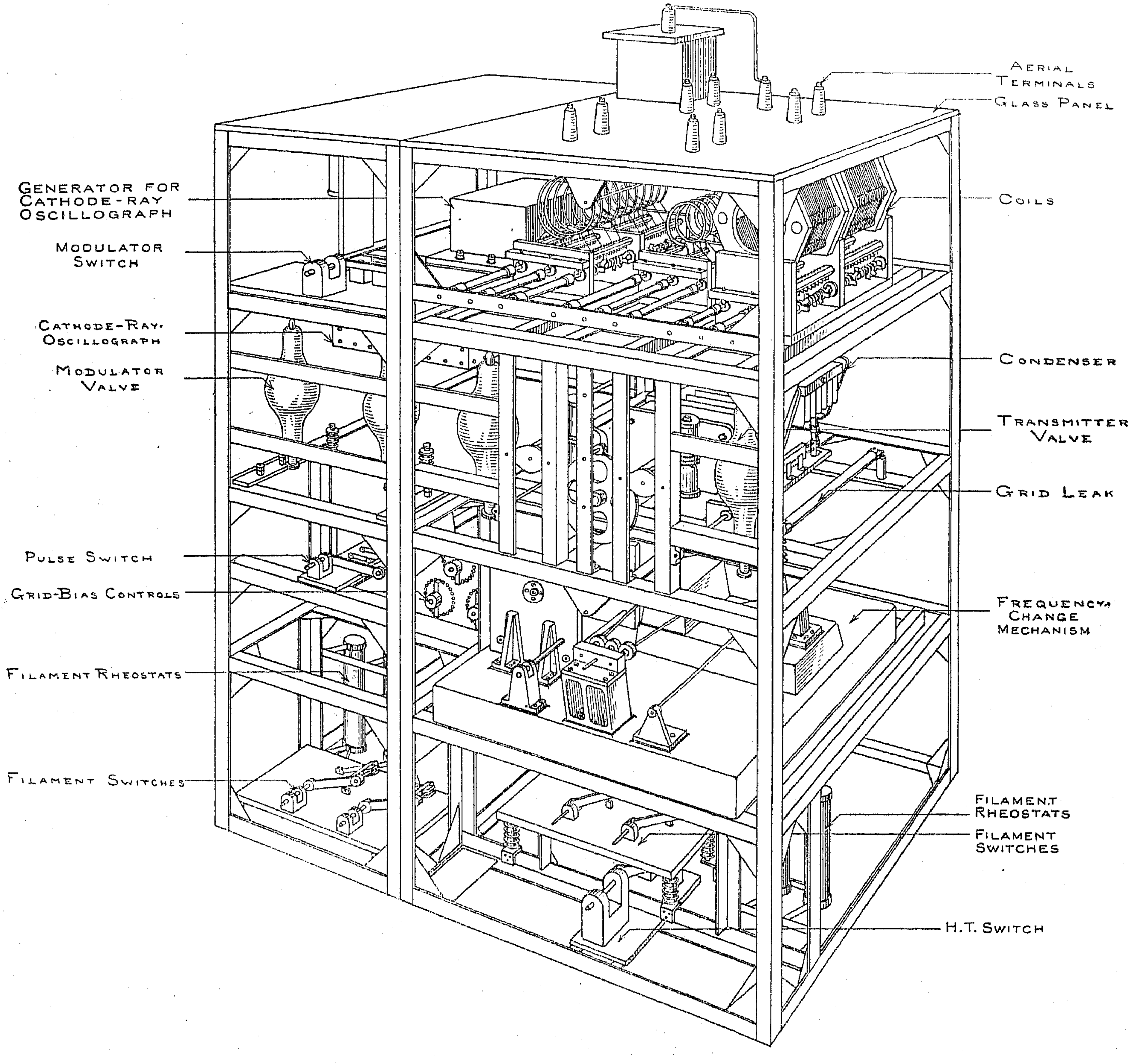

Fig. 3.—General arrangement, with panels removed.

The medium-wave coil having an inductance of about 50 μH is constructed similarly of 20 turns of $\frac{1}{4}$ in. diameter copper rod, the diameter of the turn being 6 in. and the turn spacing $\frac{3}{4}$ in., while ten tapping positions are used on each side of the centre tap.

The long-wave coil has an inductance of about 500 μH and consists of 40 turns of No. 14 S.W.G. copper wire wound on a hexagonal keramot former with a circumscribed diameter of 13 in. and a turn spacing of $\frac{3}{8}$ in.

Ten tapping points on either side of the centre tap are provided, the coil being tapped every two turns. In this case, the keramot cheeks are extended to hold the former for the coil. The long-wave coil is used for the range 250–1 200 kilocycles per sec. (1 200 to 250 metres), the medium-wave coil for 1 200–3 750 kilocycles per sec. (250–80 metres), and the short-wave coil for 3 750–6 000 kilocycles per sec. (80–50 metres). In order to cover these ranges of frequencies the main tuning variable air condenser was constructed in two sections, which may be used either singly or in parallel. This condenser is provided with mycalex insulation, and the capacitance of each section is 600 $\mu\mu$F.

(*b*) *General Lay-out.*

Referring to Fig. 3, which shows a perspective view of the whole transmitter with the front panels removed, it will be seen that the general construction comprises two frames built up from $1\frac{1}{2}$ in. × $\frac{1}{4}$ in. angle iron with corner gusset plates riveted to the angle iron. The transmitter frame and the modulator frame are both divided into four compartments on shelves, the top right-hand shelf containing the three coils described above. The short-wave coil occupies the central position in order that the leads to the condenser may be made short. The two anode taps, two aerial taps, and earth connection, are taken from each coil to a 5-point 3-way selector switch just below the short-wave coil. The aerial and earth connections are taken to a 4-way 2-pole aerial switch, the leads from which are taken to terminal posts mounted on a large glass panel at the top of the transmitter.

The second shelf contains the main variable air tuning condenser with its paralleling switch. This condenser has a slow-motion drive controlled from the front panel. The two 500-watt transmitting valves are mounted near the front panel, and the leads are taken to insulated terminal posts, while the grid leaks are supported on insulated frames as shown in Fig. 3.

The third shelf contains the frequency-change mechanism, mounted on a cast-iron base-plate forming a separate unit which can be removed. The method of operation of this portion of the apparatus is described in detail in a later section. The 2-way double-pole switch for interchanging the variable-frequency condensers is mounted at the top of this shelf just below the main tuning condenser.

The bottom shelf is devoted to the main high-tension switch, the two filament switches, rheostats and ammeters, the smoothing circuit for the H.T. supply, a remote-controlled mercury-break H.T. auxiliary switch, and, at the back of the shelf, the fuses for all the transmitter supplies.

The modulator is built as a separate unit, which is normally bolted to the transmitter framework. The top shelf of the modulator contains the pilot lamps and modulator switch, the function of which is to short-circuit the modulator valves when unmodulated transmissions are being used. The second shelf contains two modulator valves, which can be used either separately or in parallel. A cathode-ray oscillograph equipment is also installed on this shelf, and the screen can be viewed from the side of the modulator frame. The third shelf houses the grid-bias potentiometers, meters, and controls, and the pulse generating and controlling equipment, which is described later. The bottom shelf contains the filament switches, rheostats, and ammeters, together with the supply fuses. The general arrangement of the panels can be seen in Fig. 4. The right-hand side controls the transmitter, while the left-hand side controls the modulator.

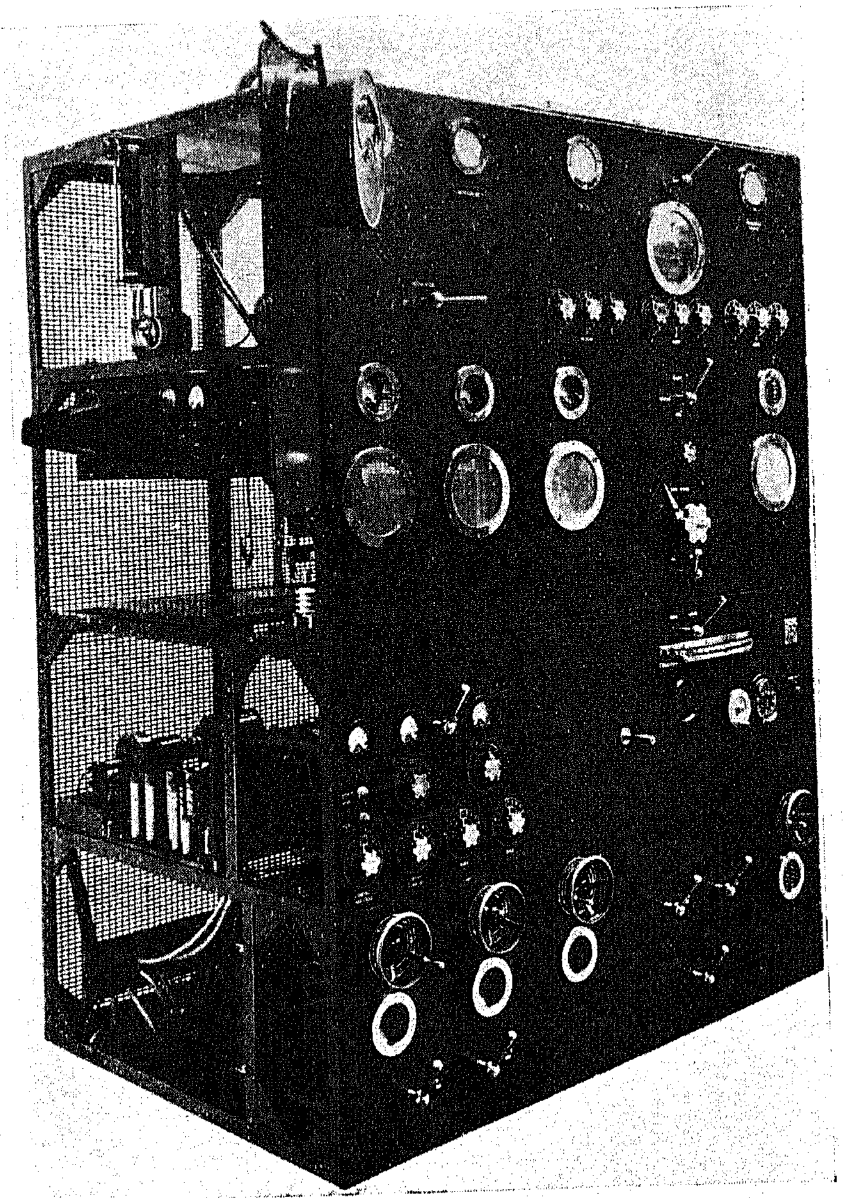

FIG. 4.—Side view of new transmitter, showing pulse mechanism and cathode-ray oscillograph.

(4) THE AUTOMATIC FREQUENCY-CHANGE MECHANISM.

As has already been explained, a small change in frequency on either side of a nominal value was required for the researches on the properties of the ionosphere, and a suitable value was found to be ± 8 kilocycles per sec. The variation in capacitance required to produce this frequency-change decreases as the wave frequency in use increases. The change is made by means of two auxiliary condensers, either of which can be connected in parallel with the main tuning condenser, the moving plates being rotated at uniform angular velocity by mechanism described below. In the case of the larger auxiliary condenser the moving vanes were made semi-circular in form, the maximum and minimum capacitances being about 250 and 30 $\mu\mu$F respectively. Since at very high frequencies the angular change required on this condenser is too small to obtain with accuracy, a second auxiliary condenser is connected to the same rotating shaft and by means of a switch either condenser can be put into circuit. This second condenser has a different construction from that of the parallel-plate type in order that its permanence of calibration may be high. The rotor and stator faces are coaxial semi-cylinders, the general arrangement being made clear by reference to Fig. 5. The stator is made in the form of a carriage which can be moved axially with respect to the rotor, and can be set in any one of four positions by means of a lock and trigger operated from the front panel. The maximum and minimum capacitances in each of the four positions are shown in the Table, the values in which correspond to an angular change of 90°. In position 4 it is possible to effect a change of $0 \cdot 033$ $\mu\mu$F per degree of rotation, which enables a sufficiently accurate frequency-change to be made at a central frequency of about 6 000 kilocycles per sec. The insulation of both these condensers consists of mycalex end-cheeks, and roller bearings are fitted to ensure precision of action.

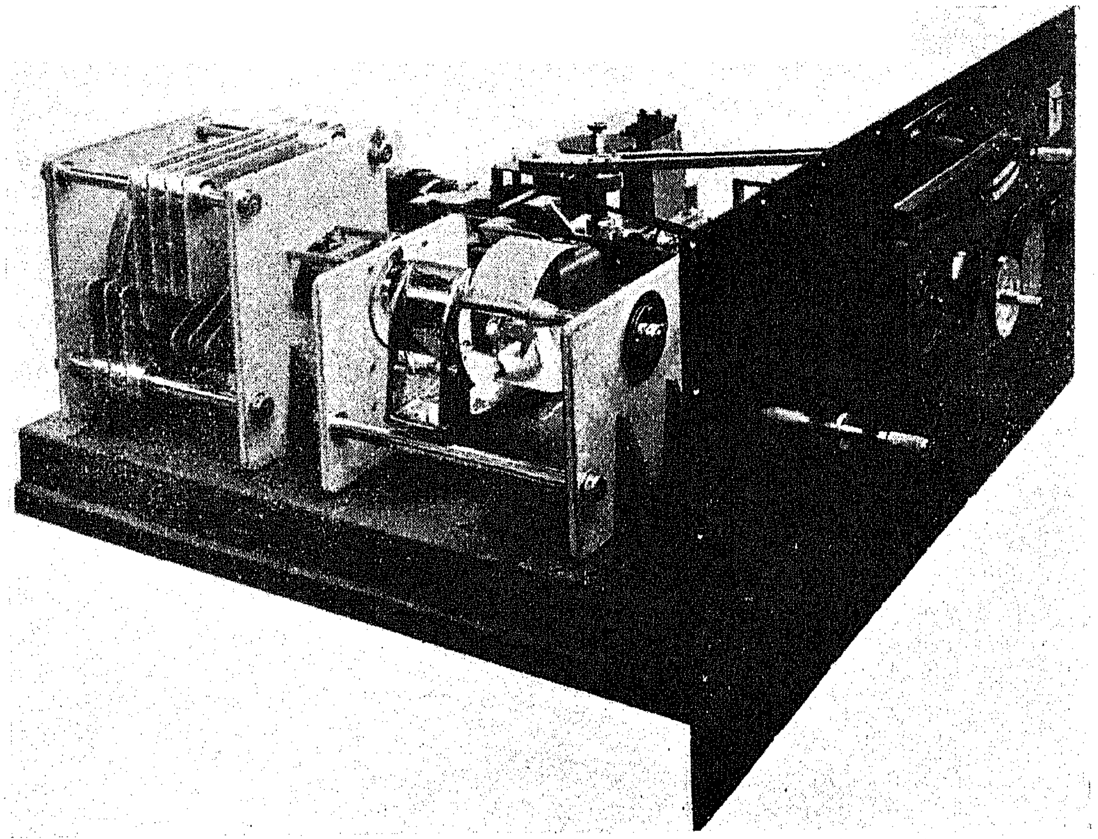

FIG. 5.—Frequency-change mechanism incorporated in new transmitter.

TABLE.

Position	Maximum capacitance	Minimum capacitance
	$\mu\mu$F	$\mu\mu$F
1	20	5
2	15	4
3	10	3
4	5	2

The inertia of the moving system is reduced by using aluminium vanes in order to ensure rapid acceleration at the ends of the stroke.

The automatic mechanism for imparting the desired rotary motion to these two auxiliary condensers is shown schematically in Fig. 6. For simplicity, only one condenser is shown in this diagram, the stator and rotor being designated by S and R respectively. The desired rotary motion is converted into a linear motion by the rack and pinion T, the teeth of which are cut helically to give a smooth action. This rack is connected, by an insulated link L_1, to the carriage X, which slides between the three guides Y. The guides of this carriage are lapped carefully to prevent any lateral movement.

The desired motion is obtained from a d.c. motor running at 1 500 r.p.m., geared to the cam C, which rotates at a speed of 1 revolution in 10 sec. This cam operates upon the follower E, sliding in the guide G, the contact between the cam face and the follower being made through a hardened-steel roller. Any desired timing can be used, but at present the frequency-change is timed to occupy 2 sec. for the total change of 16 kilocycles per sec., followed by a stationary frequency interval of 3 sec., after which the above procedure is repeated in the reverse direction. The cam edge is cut so that the velocity of the follower is constant during the change. A small notch N has been cut in the cam so that at the receiving station the frequency change which follows this signal may be identified as an increase in frequency. The motion of the follower is transferred to the rocking arm A, which is free to turn about the fulcrum F. The link L_2 in turn communicates this motion to the carriage, and thus to the condenser. The position of L_2 is made adjustable by means of the lead screws D, which are capable of rotation together by means of the universal joints U, the telescopic control rods Z, and the gears B. The link can thus be adjusted at will by turning the calibrated stroke-control hand-wheel, with the mechanism in motion or at rest. When the link L_2 lies on the fulcrum F, no motion is imparted to the condenser, while in the position shown the maximum rotation of nearly 180° is given to the condenser. The cam follower is kept in contact with the cam by the weight W, which also serves to remove backlash in the pins of link L_3, while backlash in the remaining links is removed by the spring K. Adjustments are provided so that when the cam follower is on the highest part of the cam the two lead screws are parallel, and, in this position, link L_2 can be moved without altering the position of the condenser. All the adjustments are made by means of the stroke control, which is set at zero when link L_2 lies over the fulcrum F. This adjustment can be set to 1 part in 2 000 by means of geared dials mounted on the front panel. On each nominal frequency, the stroke control is adjusted to give the required frequency-change as measured by a multivibrator, and for normal transmissions this setting is obtained for each frequency. A speed counter and motor field rheostat are provided for speed adjustment, and a hand-controlled clutch enables the position of the cam follower to be set accurately for calibration purposes.

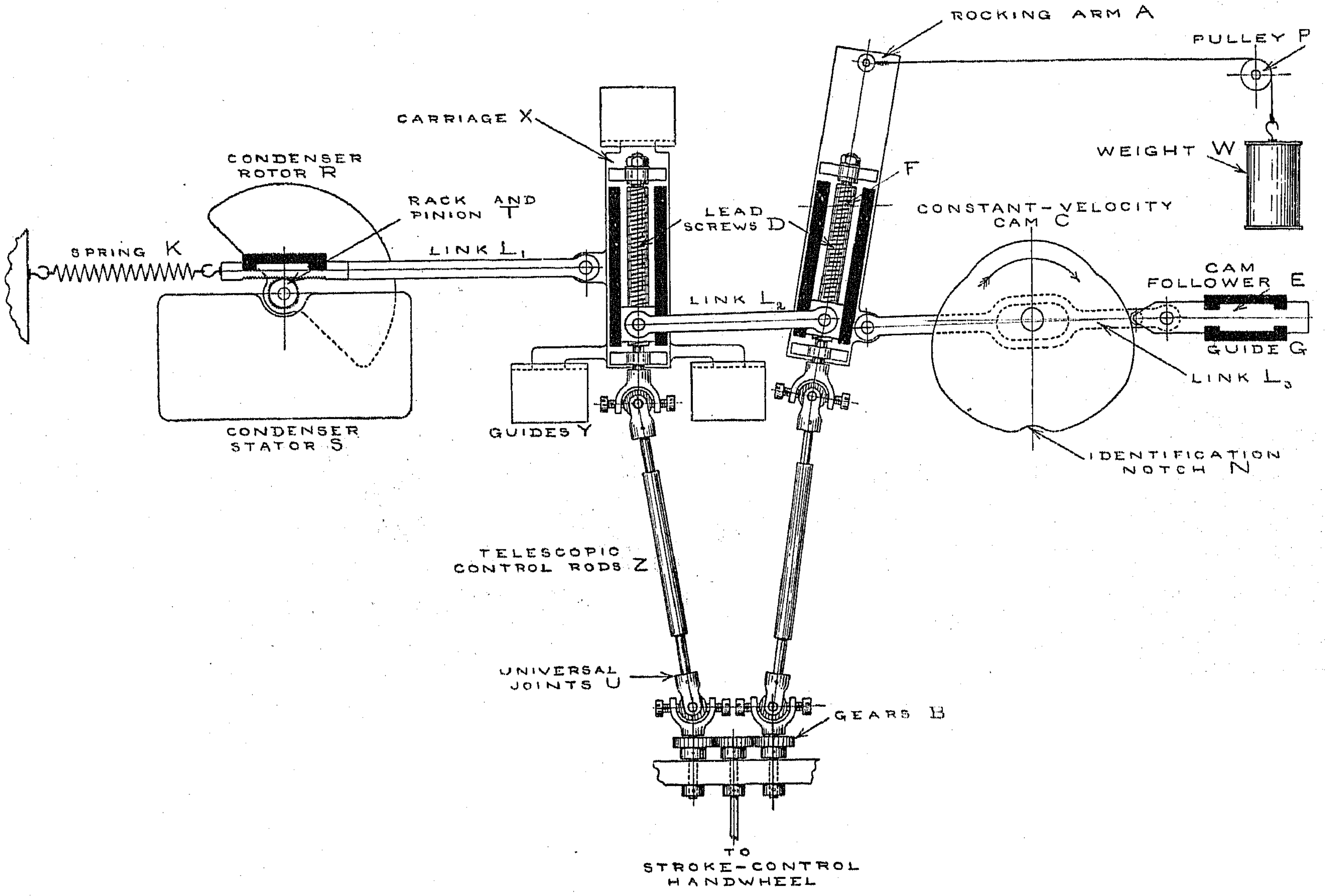

FIG. 6.—Schematic diagram of frequency-change mechanism.

Great care was taken with the design and construction of the guides and links, since the operation of the mechanism is dependent upon small tolerances at these points.

(5) Development of the Pulse Emitter.

The automatic recording methods used for continuous recording of pulse "echoes" necessitate exact synchronism between the emitted pulse frequency and the time-base applied to the cathode-ray oscillograph at the receiver. This synchronism could be obtained by the use of standard electrically-maintained forks at the transmitter and the receiver, or one fork could be used and a separate radio channel employed to "lock" the time-base to the fork frequency. Both methods are somewhat complicated and would be required in many cases, but fortunately in this country the development of synchronized a.c. supply has made possible the use of the supply mains as a frequency standard. Although the frequency constancy of the a.c. mains is not high, the fact that in many cases the emitting station and the receiving station are fed from a common supply makes exact synchronism possible.

Two possible methods of generating short pulses of constant frequency locked to the a.c. supply mains have already been described in connection with certain aspects of ionospheric research. In the first of these methods, due to J. F. Herd,* the self-oscillating system is "triggered" by applying an a.c. voltage to the anode circuit in place of the normal d.c. supply; for voltages above a few hundred volts, a thyratron was employed in the anode circuit to start the oscillations abruptly at a definite point of the anode-voltage cycle. From the paper referred to, it appears that this latter method is not very satisfactory for a high-power transmitter, owing to variations in the leakage resistance of the grid circuit. The method involves the use of a high-voltage thyratron valve and a high-voltage transformer, and, in view of the liability of such a system to give trouble due to leakage, with consequent shifting of the exact time at which the pulse occurs, it was considered that the method was not suitable for the present purpose. The second method, described by J. A. Ratcliffe and E. L. C. White,* makes use of a series modulator in which the normally negative voltage on this valve is made positive for a short duration by means of a damped wave started at regular intervals by a thyratron valve. The voltage released periodically by this valve excites a damped resonant circuit, and the first pulse of voltage is amplified and applied to the modulator grid. Although this method does not require the substitution of a transformer for the d.c. high-tension supply to the transmitter, it does involve a considerable amount of apparatus, including a thyratron valve whose striking voltage is somewhat indeterminate.

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* "The Generation and Reception of Wireless Signals of Short Duration," *Proceedings of the Physical Society of London*, 1933, vol. 45, p. 221.

Both methods attempt to solve the problem by purely electrical means, and it was considered advisable to study the possibility of using a simple contactor device. The main advantages of this arrangement are that the frequency of the pulses can be altered more readily, and that no serious modification of the transmitter circuit is involved.

Various methods involving the breaking of the grid circuit of the transmitter were examined, but were found to be unsatisfactory owing to the very high insulation required during the "break" of this circuit and also owing to grid-current sparking. The use of series modulating valves was then considered, and was found to give the most likely solution. By operating on the grid of such a modulator valve, the series resistance offered by the valve can be varied at will, and the required operating range is only of the order of 600 volts. Attention was devoted, therefore, to the production of a short pulse of about 600 volts in amplitude to be inserted in the grid circuit of the modulator valve having a normal negative bias, so that the grid would be raised in potential momentarily and then restored to its normal negative value. The induced voltage obtained in the secondary circuit of a step-up transformer in which the primary circuit is closed and opened periodically by a switch can be modified into the form of a practically unidirectional pulse of short duration by suitable resistance damping. The large pulse is obtained at the "break" in the primary circuit, and the reverse voltage obtained at "make" will not produce any effect in the modulator, since the normal negative bias is such as just to prevent anode current with full anode voltage, and the reverse pulse merely makes the grid more negative with respect to the filament. Accordingly, the secondary circuit of a transformer was inserted in series with the grid leak of the modulator valve, and the grid of this valve could be raised in potential from its normal negative value to zero during the pulse of voltage obtained at each primary break. This method of generating signal pulses would be entirely satisfactory if a large modulating valve could be used in which, with zero bias, the anode conductance was sufficiently high to give a small voltage-drop across the modulator, but it appears that a valve possessing such characteristics is at present unobtainable. With the modulating valves used, it is necessary to apply about + 200 volts to the grid to obtain a conductance high enough to give an output of 90 per cent of that obtained when the modulator valve is short-circuited, and with this bias the grid current is considerable.

The pulse envelope is determined by the shape of the secondary-circuit wave-form, and this is only satisfactory when the transformer is giving no current output. The impedance of the secondary circuit prevents any rise in grid voltage above zero due to the presence of grid current, and hence the direct connection of the transformer secondary into the grid circuit of the modulator is unsatisfactory if the full power output of the oscillator is to be obtained at the peak value of the pulse envelope. Accordingly, the modified form illustrated in Fig. 1 has been adopted. A low-resistance power valve is connected across the morse key, and the resistance of this valve is controlled by varying the grid bias by means of the pulse signal. A negative bias of 100 volts applied to this valve gives an effective resistance which is high compared with the modulator leak resistance of 100 000 ohms, and, when a pulse voltage having a peak value of 100 volts is applied, the grid-bias potential rises to zero, when the resistance of the valve is low compared with the leak resistance. In this way the excursion of the modulator grid-potential is made to be 600 volts, by means of a pulse signal of 100 volts with no current loading on the secondary circuit of the transformer.

In the early experiments, the primary make and break was obtained by using a commercial motor-car distributor contact-maker driven by a synchronous motor supplied from the a.c. mains. An examination of the secondary voltage by means of a cathode-ray oscillograph showed that a secondary shunt resistance of 100 000 ohms produced an aperiodic pulse of the desired duration, but this pulse was attended by several smaller secondary pulses which occurred at a short interval after the main pulse. This effect was found to be due to slight bouncing of the contacts, and, although various efforts were made to eliminate this trouble, no amount of spring loading was found to succeed in producing a single aperiodic pulse.

The problem thus resolved itself into the production of a satisfactory contactor for a current of about 100 mA through the primary of the transformer. In view of the difficulties of dissimilar wear resulting from the use of a metal contact disc with a soft insulating sector, the first control contact wheel employed consisted of a flat stainless-steel disc with four glass insulating bushes, the whole being carefully lapped to give a very smooth surface. The hardness of the glass insulator was of the same order as that of the steel, and it was hoped that the nature of the surface would not be affected by wear due to the brush. Both soft-copper and carbon brushes were tried, but in each case the contact between the brush and the steel was found to deteriorate after several hours' running. This was traced to the abrasive action of the glass, which appeared to load the brush with tiny glass particles

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* "An Automatic Recording Method for Wireless Investigations of the Ionosphere," *ibid.*, 1933, vol. 45, p. 399.

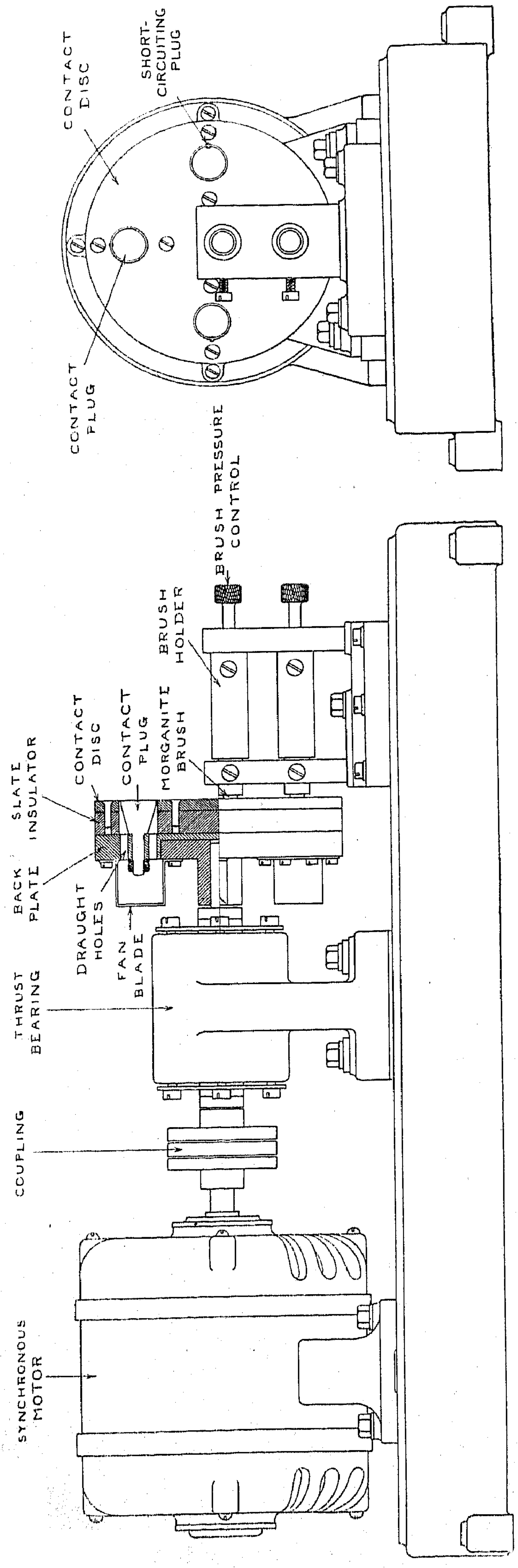

FIG. 7.—General arrangement of contactor for pulse emitter.

and form an insulating film thereon. This difficulty rendered such a contactor unsatisfactory, and demonstrated quite clearly that the insulating bushes must be made of the same material as the rest of the disc.

The final arrangement is shown in Fig. 7. The a.c. synchronous motor drives the stainless-steel contact disc through a flexible coupling and a thrust bearing. This bearing is necessary to prevent end-play, which would cause chatter on the brush. The contact disc is bolted to an insulating disc, which in turn is bolted to the back plate pinned to the shaft. Four contact plugs are bolted to the back plate and project through to the outer surface of the front plate, from which they are insulated by an annular air-gap $\frac{1}{32}$ in. wide, and by the insulating disc. Two brushes made of morganite are spring-loaded to make contact between the front plate and the contact plugs. When the lower brush lies on a contact plug, the primary circuit of the transformer is broken, and when the brush passes the small air-gap between the plug and plate, contact is made. The advantages of this arrangement are that the wear is negligible, and that there is no " wiping " action as was experienced with the previous discs. In order to prevent tiny particles of the brush from blocking the air-gap, a series of draught holes and small fan blades are arranged in the back plate so that a high-velocity stream of air is forced through each gap in such a manner as to clear any obstructing particles (see Fig. 7). Each of the four contact plugs is provided with a short-circuiting plug which can be screwed into the disc face so as to make any plug electrically continuous with the disc. By this means the frequency of the pulse can be made 100, 50, or 25 cycles per sec. In the first model of this contactor the insulating disc was made of keramot, and it was found that the expansion of this disc caused by temperature changes produced a movement of the contact disc face with respect to the contact plugs sufficient to cause bad chattering of the brush. A slate insulator having a very low temperature

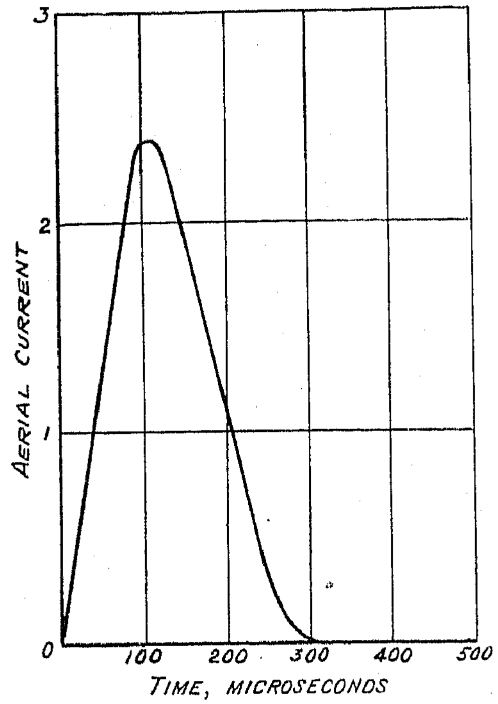

FIG. 8.—Shape of pulse envelope.

coefficient of expansion was then introduced which eliminated this difficulty.

The final arrangement has been used very considerably and has given entire satisfaction. The pulse is quite steady in both amplitude and duration, and the only attention required is an occasional cleaning of the contact disc. The shape of the pulse envelope as seen by the cathode-ray oscillograph is shown in Fig. 8, where the time-scale is in microseconds and the aerial-current scale in arbitrary units. The shape of this envelope can be varied within appreciable limits by altering the value of the shunt resistance across the secondary circuit of the step-up transformer.

Since the resistance in series with the contact is considerable, the rate of growth of the current in the primary circuit of the transformer is as rapid as the rate of fall of current. Two pulses of opposite sign are generated as the brush passes over each plug, and since the negative pulse will not produce modulation, the grid being already biased to give zero oscillatory current, either pulse can be used for the modulating signal. It has been found preferable to make use of the pulse produced at the make, since less sparking occurs at this point and consequently the continuity of the signal is more definite.

(6) CATHODE-RAY OSCILLOGRAPH EQUIPMENT.

For pulse transmissions, the r.m.s. value of the aerial current is too small to give a deflection on the aerial ammeter normally used in the set, and, although the pulse signal can be rectified and heard in telephones, such a procedure gives no indication of any intermittent failure of the pulse generator, and insufficient indication of the character of the pulse.

It was considered advisable to install a cathode-ray oscillograph equipment whereby the form of the modulated wave could be inspected while the transmitter was in operation. A further use for such an equipment is the examination of the depth of modulation in cases where simple sine-wave modulation of the transmitter is used. The equipment provided follows conventional oscillograph technique. A low-voltage tube (500–1 000 volts) is used, housed in a metal screening box with a convenient observational eyepiece which enables the operator to observe the screen without darkening the transmitting hut. The horizontal time-base is derived directly from the 50-cycle supply mains, so that the motion of the spot in the horizontal direction is of a simple harmonic character. The vertical-deflection electrodes of the tube are connected directly across a small damped tuned circuit coupled very loosely to the aerial. The image obtained therefore gives a direct picture of the modulated envelope, from which the amplitude and period of the pulse can be determined. Since the pulse is synchronized to the a.c. supply mains, the image normally remains perfectly stationary and any irregularity in the emission is immediately noticed. The general arrangement of the oscillograph equipment is shown in Fig. 4, which also indicates its disposition relative to the modulator framework. The rheostat and switch directly above the oscillograph control the h.t. motor-generator housed on the top shelf of the modulator, and the wooden platform below the equipment is used for the l.t. battery for the tube.

(7) MODULATION AND POWER AMPLIFICATION.

As previously mentioned, the modulator is an entirely separate piece of apparatus and can be thrown out of action by putting the modulator switch to the "Off" position. In this position the anodes of the two valves are connected directly to the earthed filaments. The grid bias for the modulator is provided by a 600-volt machine which supplies a potentiometer, tappings from which give any desired negative and positive biasing potential difference. For pulse emission, the negative bias adopted is 400 volts, this value being sufficient to prevent oscillation in the transmitter. A positive voltage of 200 volts is used for key signalling.

For the first type of standard-frequency emission in which the standard tuning fork is used to produce modulation, at a frequency of 1 000 cycles per sec., the grid bias is adjusted to give an aerial current equal to about one-half of that produced with the 200-volt positive bias used for keying. The amplified 1 000-cycle wave is applied to the grid of the modulator valve, and the depth of modulation so produced can be observed directly by means of the cathode-ray oscillograph equipment. Full modulation (100 per cent) can be produced with very little harmonic distortion.

The second type of standard-frequency emission takes the form of a continuous-wave signal of known and steady frequency. In this case the transmitter is used as the final push-pull stage of an amplifying chain supplied from a quartz-controlled master oscillator. For this purpose, the grid leaks and coupling condensers are disconnected by means of a special switch and the grids brought to two convenient terminals to which the secondary circuit of a radio-frequency transformer can be connected. The quartz-controlled oscillator and amplifier have been built to form a self-contained unit,* and when this unit is attached to the transmitter in the above manner the requisite standard-wave emission can be obtained.

(8) CONCLUSIONS AND ACKNOWLEDGMENTS.

The transmitting installation described above has been in regular operation for a period of about 15 months, and is giving entire satisfaction. The two methods of investigating the properties of the ionosphere are in constant use in connection with the programme of work being conducted for the Radio Research Board. Under the direction of Prof. Appleton a variety of measurements are being made with the aid of the Laboratory transmitter, the recording of the received signals being carried out at the Halley-Stewart Laboratories, King's College, London, and at the Radio Research Station, Slough.

In one programme, an examination of the ionospheric conditions is made at about noon on Friday of each week throughout the year. During this test the operating frequency is increased in a series of suitable steps with a view to ascertaining the wavelength of the shortest waves returned to earth at the receiving station. In this way the height of the conducting layers and the density of ionization are determined throughout the year. This work has already been in progress for about 2 years, and it is likely to continue for a considerable period so that data may be collected over a solar cycle. The installation of the new transmitter has considerably accelerated this programme, and it is now possible to explore the ionospheric conditions with a range of 60 frequencies within half an hour.

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* L. ESSEN: "Description of the Quartz Control of a Transmitter at 1 785 kilocycles per second," *Journal I.E.E.*, 1934, vol. 74, p. 595.

In another type of programme, the ionospheric conditions are under practically continuous observation throughout a 24-hour period. For investigations of this nature, the pulse type of emission has been found to be particularly valuable, since with a cathode-ray oscillograph in operation at the receiving end, and a synchronized time-base, a continuous watch may be kept on the time-difference between the received pulses, and so on the ionized deflecting layers. In addition to these routine programmes, various experimental transmissions are made as required in connection with the general study of the ionosphere. The use of the installation for the dissemination of standard frequencies has already been described, and the current programme of such services has been published elsewhere.*

The work described above has been carried out as part of the programme of the Radio Research Board, and this paper is published by permission of the Department of Scientific and Industrial Research. The author desires to express his appreciation of the continuous assistance given by Dr. R. L. Smith-Rose while the design of the transmitter was being evolved, and the workshop staff of the Engineering and Metrology Departments of the National Physical Laboratory in the construction and erection of the installation. He is also particularly indebted to Mr. E. L. Hatcher of the Radio Department of the Laboratory, who has been in charge of the installation, calibration, and operation, of the transmitter described in this paper, and who now maintains all the regular services for which the present installation is employed.

INSTITUTION NOTES.

Council for the Year 1934–1935.

The scrutineers appointed at the Ordinary Meeting held on the 26th April, 1934, have reported to the President that the result of the ballot to fill the vacancies which will occur in the Council on the 30th September next is as follows:—

President: Professor W. M. Thornton, O.B.E., D.Sc., D.Eng.

Vice-Presidents: W. E. Highfield, and Lieut.-Col. A. G. Lee, O.B.E., M.C.

Hon. Treasurer: F. W. Crawter.

Ordinary Members of Council: (Members) N. Ashbridge, B.Sc.(Eng.), J. R. Beard, M.Sc., V. Watlington, M.B.E., W. J. H. Wood; (Associate Members) A. H. M. Arnold, Ph.D., J. W. Thomas, LL.B., B.Sc.; (Companion) Brig.-General R. F. Legge, C.B.E., D.S.O.

The Council for the year 1934–1935 will therefore be constituted as follows:—

President.

Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng.

Past-Presidents.

Colonel R. E. Crompton, C.B., F.R.S.
Sir James Swinburne, Bart., F.R.S.
Sir Richard T. Glazebrook, K.C.B., K.C.V.O., D.Sc., F.R.S.
W. M. Mordey.
Sir John Snell, G.B.E.
Charles P. Sparks, C.B.E.
Roger T. Smith.
Ll. B. Atkinson.
J. S. Highfield.
F. Gill, O.B.E.
A. Russell, M.A., D.Sc., LL.D., F.R.S.
W. B. Woodhouse.
R. A. Chattock.
W. H. Eccles, D.Sc., F.R.S.
Sir Archibald Page.
Lieut.-Col. K. Edgcumbe, T.D.
Colonel Sir Thomas F. Purves, O.B.E.
Clifford C. Paterson, O.B.E.
J. M. Donaldson, M.C.
Prof. E. W. Marchant, D.Sc.
P. V. Hunter, C.B.E.

Vice-Presidents.

W. E. Highfield.
Lieut.-Col. A. G. Lee, O.B.E., M.C.
R. P. Sloan, C.B.E.
H. T. Young.

Honorary Treasurer.

F. W. Crawter.

Ordinary Members of Council.

A. H. M. Arnold, Ph.D.
N. Ashbridge, B.Sc.(Eng.).
J. R. Beard, M.Sc.
W. S. Burge.
Prof. J. K. Catterson-Smith, M.Eng.
P. Dunsheath, O.B.E., M.A., D.Sc.
V. Z. de Ferranti.
A. P. M. Fleming, C.B.E., M.Sc.
Brig.-General R. F. Legge, C.B.E., D.S.O.
W. McClelland, C.B., O.B.E.
E. W. Moss.
C. G. Morley New.
H. W. H. Richards.
C. Rodgers, O.B.E., B.Sc., B.Eng.
J. W. Thomas, LL.B., B.Sc.
V. Watlington, M.B.E.
W. J. H. Wood.
Johnstone Wright.

Together with the Chairman of the Wireless Section, the Chairman of the Meter and Instrument Section, the Chairman of the Transmission Section, and the Chairman and immediate Past-Chairman of each Local Centre.

Graduateship Examination Results: May, 1934.

Passed.†

Abel, H. L. (Coventry).
Andrews, W. H. (London).
Barnard, G. (Sale).
Barrass, G. S. (Fencehouses).
Bell, W. W. (Pelaw-on-Tyne).
Blackley, V. K. (Llandudno).
Campe, W. K. (Coventry).

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* "Standard Frequency Transmissions," *World Radio*, 14th Oct., 1932, p. 819; also *Wireless Magazine*, 1932, vol. 16, p. 595.

† This list also includes candidates who are exempt from, or who have previously passed, a part of the Examination and have now passed in the remaining subjects.

*Passed**—continued.

Castell, G. O. (London).
Dalton, A. J. (Dorchester).
Davies, H. C. (Ogmore Vale).
Earnshaw, W. (Rotherham).
Eatock, J. (Preston).
Everett, N. C. (Wivenhoe).
Finden, H. J. (Welwyn Garden City).
Fisher, L. (Leeds).
Gibson, M. (Hatch End).
Goldstein, S. (London).
Guscott, W. J. (Dawlish).
Heath, J. C. (Wellingborough).
Herriot, A. (Dumbarton).
Hough, G. E. (Birmingham).
Hudson, H. F. (Worcester).
Jenkins, H. J. (Loughborough).
Khanna, H. K. L. (York).
Lamacraft, J. R. (Guildford).
Lawrence, E. E. H. (Ashford, Kent).
Marslen-Wilson, D. W. (Aldbourne, Wilts).
Nally, R. M. (Dublin).
Nisbet, B. C. (London).
Nixon, H. (Portland).
Orchard, K. (Weymouth).
Powell, E. C. (Goudhurst).
Rao, K. S. (Rugby).
Rawnsley, C. F. (London).
Rogers, A. P. F. (London).
Scott, W. J. (Bridgwater).
Skerritt, M. (Nottingham).
Smith, C. H. (Rotherham).
Taha, A. A. (London).
Taylor, D. P. (Penzance).
Thomson, C. C. (Nottingham).
Warburton, E. (Retford).
Worland, F. J. (Tunbridge Wells).
Wrate, W. A. (Woodford Green, Essex).

Passed Part I only.

Bartholomew, L. J. W. (Southampton).
Boyton, E. M. (Birmingham).
Bradley, J. F. (Hawick).
Bradley, J. H. (Rawdon).
Coy, L. H. (Galway).
Dunkel, C. P. (Oxford).
Fry, M. F. (Bexley Heath).
Gillson, G. (Hillingdon Heath).
Hayward, J. R. G. (London).
Hemingway, J. W. (New Malden).
Hodges, L. W. (Pontypridd).
Lawlor, J. B. S. (Killarney).
Macaulay, A. J. (Loughborough).
New, C. M. (Bridgwater).
Possnett, A. F. J. (Welling).
Preston, H. S. (Loughborough).
Stephenson, E. (Grimsby).
Thayer, A. G. (Ilford).
Thompson, F. A. (Hartlepool).
Williams, J. C. (Cardiff).
Wilson, L. J. (Ashford, Kent).
Wood, P. T. (Bedford).

Passed Part II only.

Amos, W. J. (South Farnborough).
Chakravarti, S. S. (London).
Clark, W. B. (London).
Harris, A. W. (London).
Lombard, J. S. (Cardiff).
Whyte, A. McG. (Barrow-in-Furness).

Coopers Hill War Memorial Prize and Medal.

The Secretary desires to remind members that the latest date for submitting papers in connection with the above Prize and Medal is the 1st October.

The papers must be specially written for the purpose of the competition, which is restricted to Corporate Members of the Institution who were under 35 years of age on the 1st January last. The following 12 subjects have been selected and competitors are invited to submit a paper on any one of them:—

"The Use of Electricity in Public Works."
"Hydro-Electric Power Developments."
"Electrification of Railways."
"Electricity in Agriculture."
"Electricity in Mines."
"The Application of Electricity to Ships."
"Domestic Applications of Electricity."
"Long-Distance Telephony (excluding Wireless)."
"Long-Distance Telegraphy (excluding Wireless)."
"Overhead Lines in Rural Districts."
"Empire Wireless Communications."
"Television."

Electricity Commissioners' Regulations, and Amended British Standards for Cables.

The Electricity Supply Regulations recently issued by the Electricity Commissioners prescribe that no electric lines or circuits shall be brought into use "unless the insulation of every part thereof has withstood either (i) the tests prescribed in that behalf in the appropriate specification of the British Standards Institution then current, or . . ." To comply with the strict letter of this requirement would involve subjecting all service lines to the 15-minute high-voltage test specified in the B.S. Specifications for cables, i.e. B.S.S. No. 7 and B.S.S. No. 480. When these specifications were drafted there was no intention that short service lines should be subjected to the 15-minute test, and confusion has therefore sometimes arisen regarding the interpretation of the Regulations in the light of the B.S. Specifications, and vice versa.

To clarify the position, revision slips have been issued, at the request of the Electricity Commissioners, exempting short service lines from certain tests. These revision slips also deal with certain other matters. Thus, the revision slip CD(EL)3769 (for B.S.S. No. 7) deals with the dimensions of armouring wires and gives the dimensions of 600-volt jute-insulated cables which were omitted from a recent reprint of the specification. The slip CD(EL)3768 (for B.S.S. No. 480) corrects an important omission in the clause dealing with the application of the voltage test.

Copies of these revision slips will be forwarded gratis on receipt of a stamped addressed envelope by the Publications Department, British Standards Institution, 28 Victoria Street, London, S.W.1.

Accessions to the Reference Library.

[Note.—The books cannot be purchased at the Institution; the names of the publishers and the prices are given only for the convenience of members. (*) denotes that the book is also in the Lending Library.]

ALLCOCK, H. J., and JONES, J. R., *M.A.* The nomogram. The theory and practical construction of computation charts. 8vo. viii + 209 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1932.) 10*s.* 6*d.*

APPLEYARD, *Commander* R., *O.B.E.*, *J.P.* Charles Parsons, his life and work. 8vo. xiii + 334 pp. (London: Constable and Co., Ltd., 1933.) 15*s.* (*)

ARNOT, F. L., *Ph.D.*, *F.R.S.E.* Collision processes in gases. sm.8vo. viii + 104 pp. (London: Methuen and Co., Ltd., 1933.) 3*s.*

---

* This list also includes candidates who are exempt from, or who have previously passed, a part of the Examination and have now passed in the remaining subjects.

Baize, P. Les parasites en T.S.F. Procédés les plus efficaces pour l'élimination des parasites industriels. sm.8vo. 91 pp. (Paris: Etienne Chiron, 1932.) 8 *francs*.

Bardtke, P. Technique of modern welding. Transl. from 2nd German ed. by H. Kenney. 8vo. xi + 299 pp. (London: Blackie and Son, Ltd., 1933.) 15*s*. (*)

Barr, J. R., and Bolton, D. J., *M.Sc.* Principles of direct-current electrical engineering. 2nd ed. 8vo. x + 486 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1934.) 21*s*. 6*d*. (*)

Barton, A. W., *M.A.*, *Ph.D.* A text book on heat. 8vo. xiii + 378 pp. (London: Longmans, Green and Co., Ltd., 1933.) 7*s*. 6*d*.

Beetle, R. D. The McGraw-Hill five-place logarithmic and trigonometric tables. Prepared under the editorial supervision of R. D. B. 8vo. vii + 131 pp. (New York, London: McGraw-Hill Book Co., Inc., 1933.) 5*s*.

Berkeley, G. S. Traffic and trunking principles in automatic telephony. 8vo. xi + 241 pp. (London: Ernest Benn, Ltd., 1934.) 10*s*. 6*d*. (*)

Bersey, W. C. Electrically-propelled vehicles. (*With a collection of photographs of early vehicles appended.*) 4to. 83 pp. (London: Morgan, Thompson, and Jamieson, 1898.)

Biggs, H. F., *M.A.*, *M.Sc.* The electromagnetic field. 8vo. viii + 158 pp. (Oxford: Clarendon Press, 1934.) 10*s*. 6*d*.

Booth, E., *M.C.* An elementary introduction to physics. 8vo. xvi + 465 pp. (Glebe, N.S.W.: Australasian Medical Publishing Co., Ltd.; London: H. K. Lewis & Co., Ltd., 1932.) 5*s*.

Bragg, *Sir* W. H., *O.M.*, *K.B.E.*, *D.Sc.*, *F.R.S.*, and Bragg, W. L., *D.Sc.*, *F.R.S.* The crystalline state. vol. 1, A general survey, by W. L. B. 8vo. xiv + 352 pp. London: G. Bell and Sons, Ltd., 1934.) 26*s*. (*)

Bunet, P. Courants de Foucault. Résistance effective en courant variable—Effet Kelvin ou de peau—Conducteurs uniques rectilignes—Noyaux magnétiques. sm.8vo. 180 pp. (Paris: Librairie J. B. Baillière et Fils, 1933.) 25 *francs*.

Burger, O. Berechnung von Gleichstrom-Kraftubertragungen. 8vo. viii + 82 pp. (Berlin: Julius Springer, 1932.) *RM*. 6.40.

Bushnell, C. H. Diesel engine operation, maintenance and repair. 8vo. viii + 285 pp. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1930.) 21*s*. 6*d*.

Cameron-Brown, C. A., *B.Sc.* The use of electric heating cables for hot-beds. 2nd ed. Institute for Research in Agricultural Engineering, Univ. of Oxford. 8vo. 47 pp. (Oxford: Institute for Research in Agricultural Engineering, 1934.) 1*s*.

Clayton, A. E., *D.Sc.(Eng.)*. Alternating currents. 2nd ed. 8vo. viii + 334 pp. (London: Longmans, Green and Co., 1934.) 10*s*. 6*d*. (*)

—. Power factor correction. 2nd ed. sm.8vo. xi + 128 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1934.) 2*s*. 6*d*. (*)

Comité Consultatif International des Communications Téléphoniques à Grande Distance. Plenary session, Paris, 14th–21st Sept., 1931. English edition. 4to. viii + 362 pp. (London: The International Standard Electric Corporation, 1932.) 21*s*.

Conférence Internationale des Grands Réseaux Electriques à Haute Tension. Compte rendu des travaux de la 7^{e} session, 16–24 juin, 1933. Etabli par J. Tribot-Laspière. 3 tom. 8vo. (Paris, Avenue Marceau, 54: Conférence Internationale des Grands Réseaux Electriques, 1933.) 375 *francs*.

Cork, J. M., *Ph.D.* Heat. 8vo. xi + 279 pp. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1933.) 18*s*.

Cricks, R. H. The complete projectionist: a textbook for all who handle sound and pictures in the Kinema. Edited by A. J. Martin. sm. 8vo. xxii + 237 pp. (London: Kinematograph Publications, Ltd., 1933.) 5*s*. (*)

Davies, C. W., *D.Sc.* The conductivity of solutions. 2nd ed. 8vo. x + 281 pp. (London: Chapman and Hall, Ltd., 1933.) 15*s*. (*)

Davis, A. F. Designing for arc welding. Second Lincoln Arc Welding Prize Competition papers. Edited by A. F. D. 8vo. xii+424 pp. (Cleveland, Ohio: The Lincoln Electric Co., 1933.) $2.50. (*)

De Leeuw, A. L. Rambling through science. 8vo. 320 pp. (New York, London: McGraw-Hill Book Co., Inc., 1932.) 10*s*. 6*d*. (*)

Diesel Engine. The modern Diesel: a review of high speed compression ignition engines for road transport, aircraft and marine work. 2nd ed. sm. 8vo. ix + 184 pp. (London: Iliffe and Sons, Ltd., 1933.) 3*s*. 6*d*.

Dwight, H. B., *D.Sc.* Tables of integrals and other mathematical data. 8vo. viii + 222 pp. (New York: The Macmillan Co., 1934.) 8*s* 6*d*.

Eddington, A. S., *LL.D.*, *D.Sc.*, *F.R.S.* Space, time and gravitation: an outline of the general relativity theory. 8vo. vi + 218 pp. (Cambridge: University Press, 1929.) 15*s*.

Elbourne, E. T. Fundamentals of industrial administration. An introduction to industrial organisation, management and economics. By E. T. E., assisted by K. B. Elbourne and P. J. Amer. 8vo. xviii + 644 pp. (London: Macdonald and Evans, 1934.) 12*s*. 6*d*. (*)

Electrical Times, Ltd. Electricity tariffs and voltages of supply undertakings in the United Kingdom, revised to January 1st, 1934. 7th ed. sm. 8vo. 122 pp. (London: "Electrical Times," 1934.) 1*s*. 6*d*.

Electricity (Supply) Act, 1933. An Act to amend section 16 of the Electricity (Supply) Act, 1919, and section 21 of the Electricity (Supply) Act, 1922. 8vo. 2 pp. (London: H.M. Stationery Office, 1933.) 1*d*.

Evans, U. R., *M.A.* The corrosion of metals. 2nd ed. 8vo. xvi + 259 pp. (London: Edward Arnold and Co., 1926.) 15*s*.

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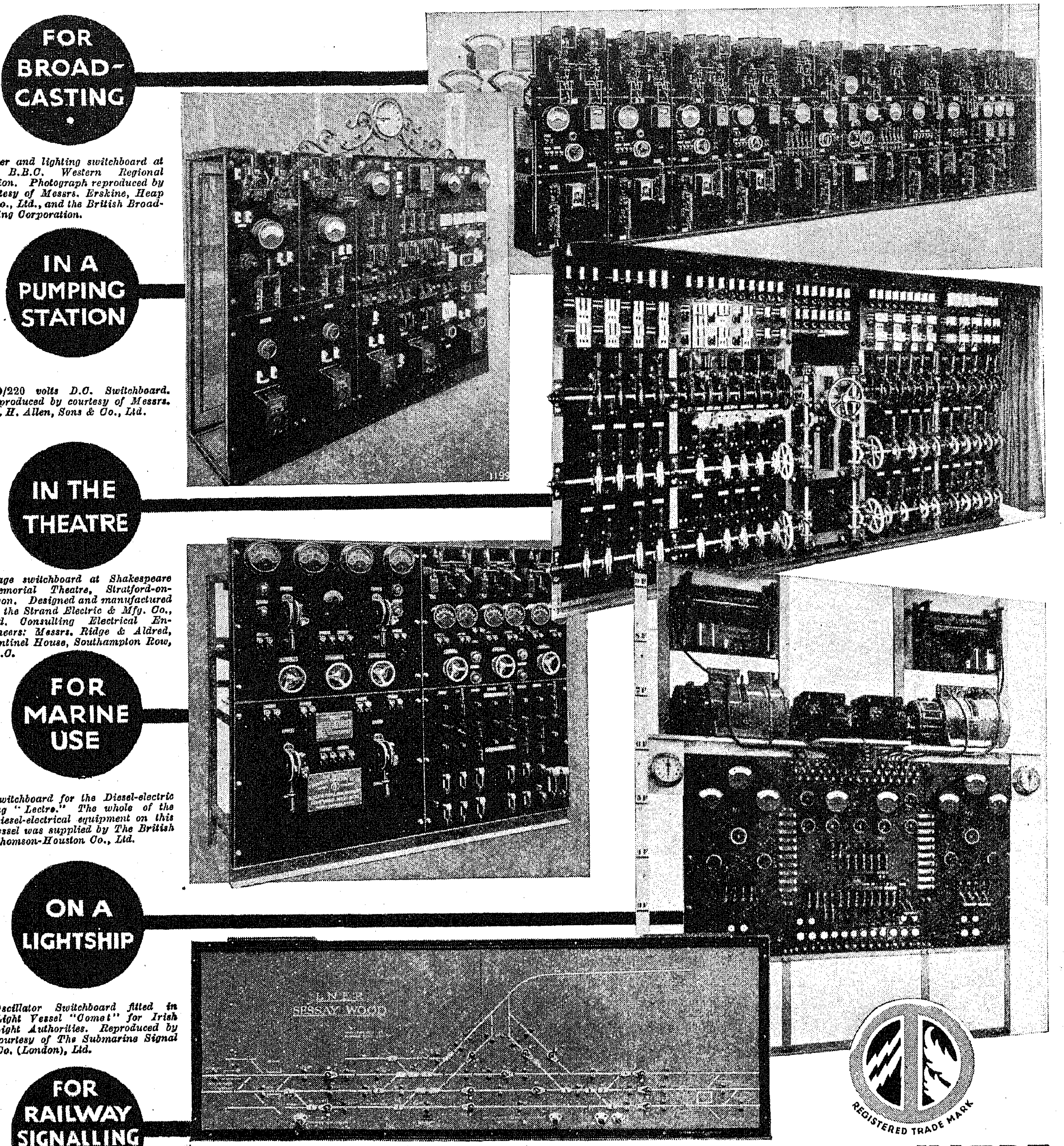

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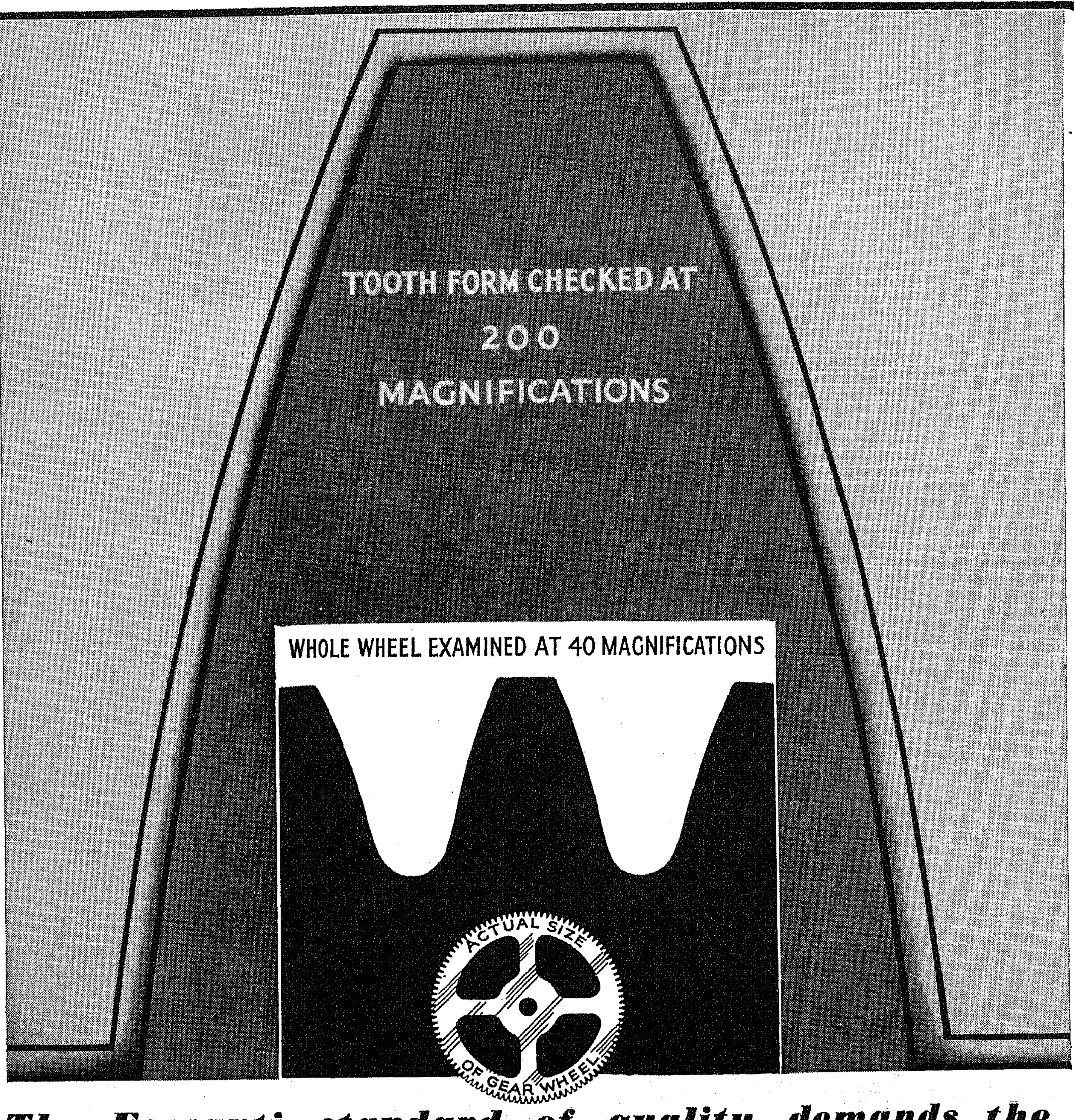
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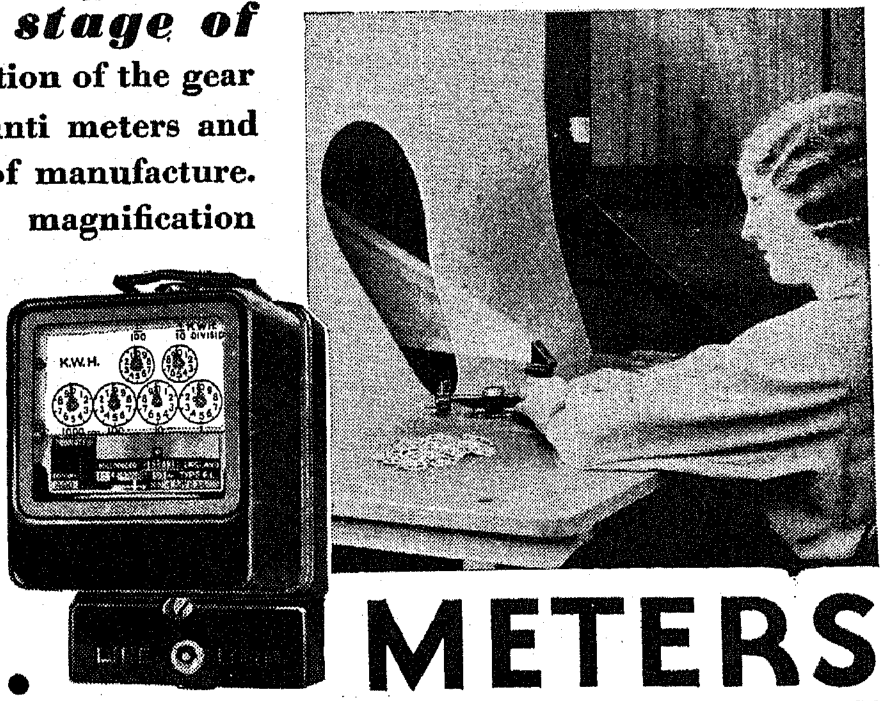

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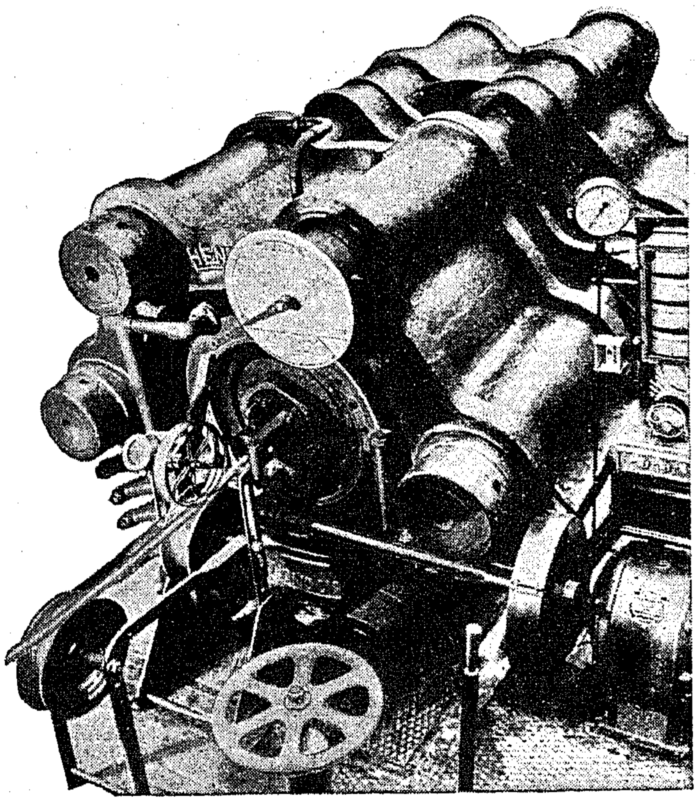

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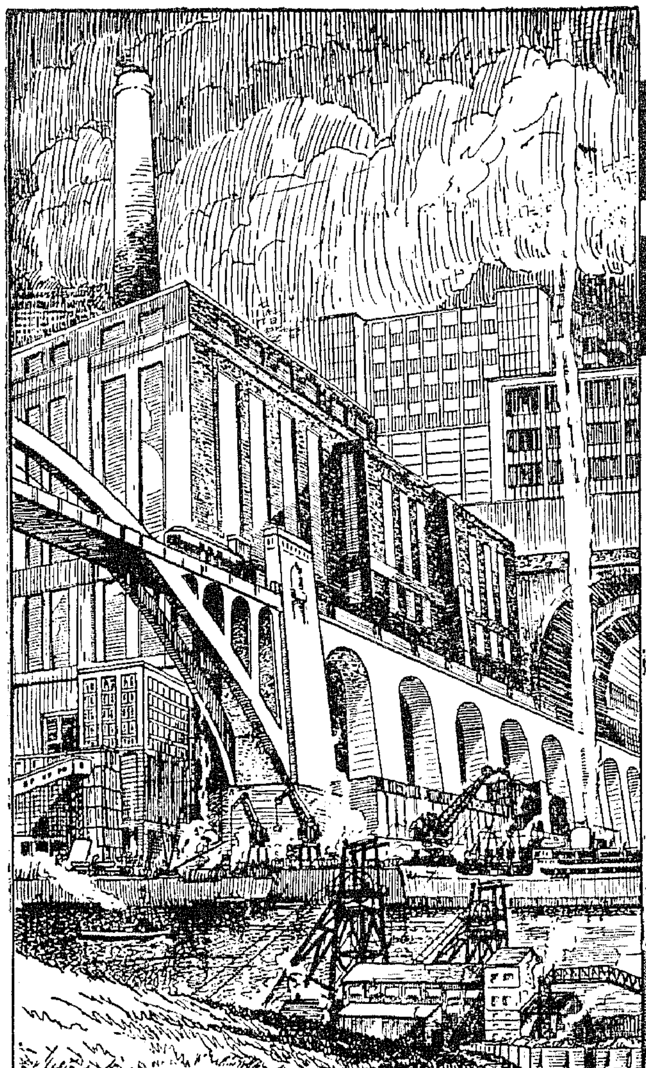

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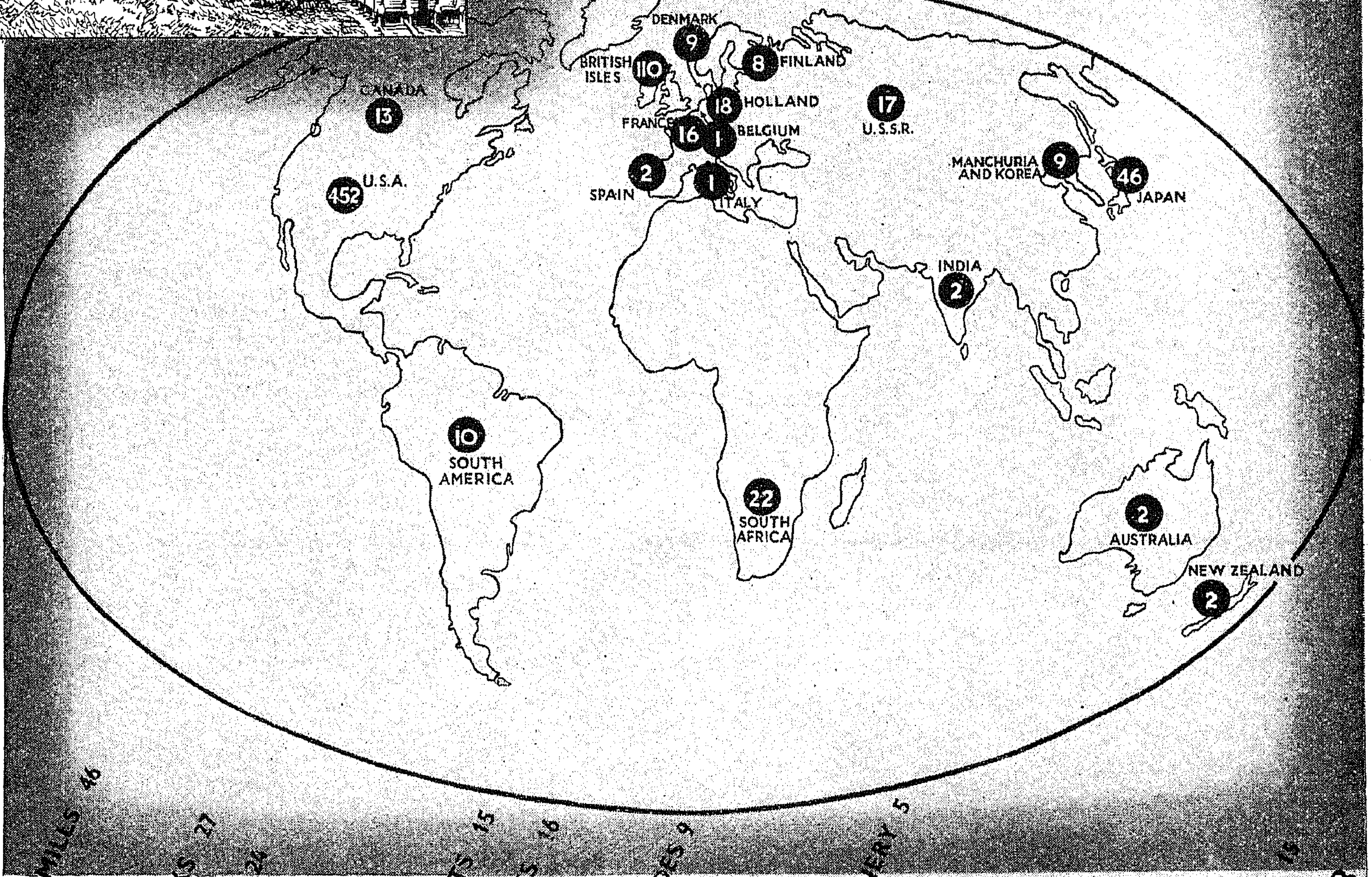

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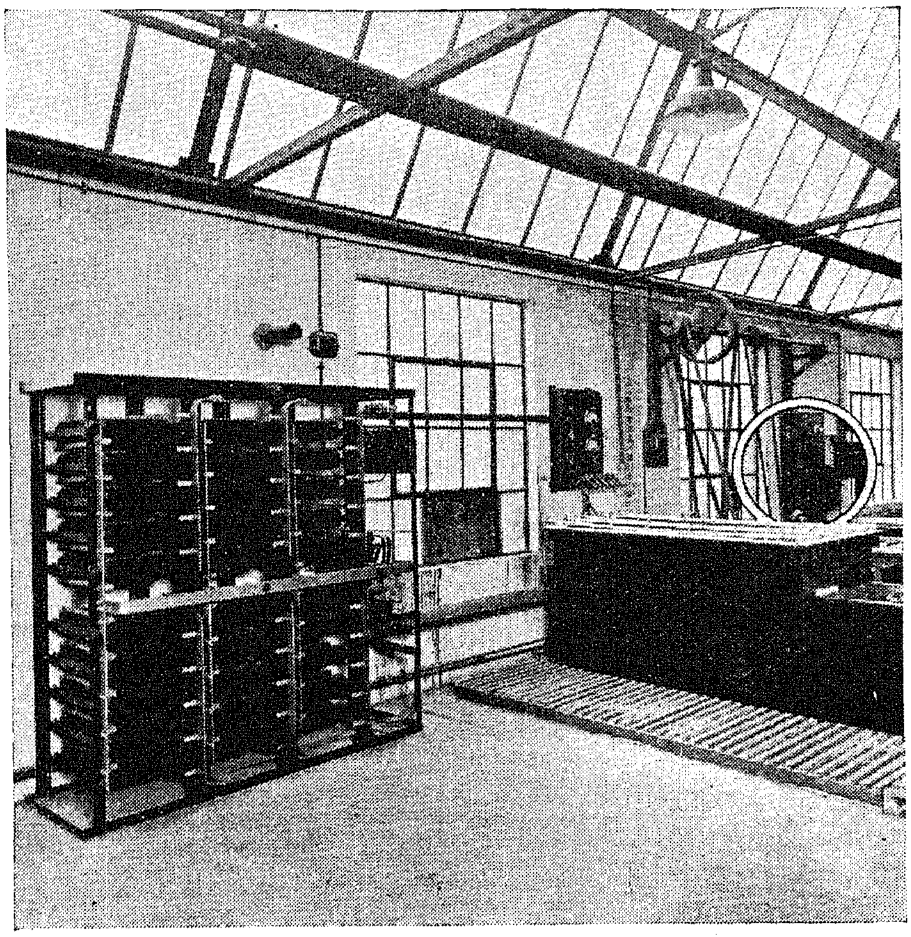

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metal rectification is used.

The illustration shows an electro-plating installation at the Slough Works of Messrs. McMichael Radio, Ltd., the famous Radio Manufacturers. The Mains Supply is 3-phase A.C., so that the load can be evenly balanced, and the D.C. output of the rectifier is 600 amps. at 6 volts. Note the smaller installation in the background. This was working continuously at full load for over five years and, as increasing business made a further rectifying set necessary, its reliability and efficiency having been tested and proved, naturally the choice was again Westinghouse.

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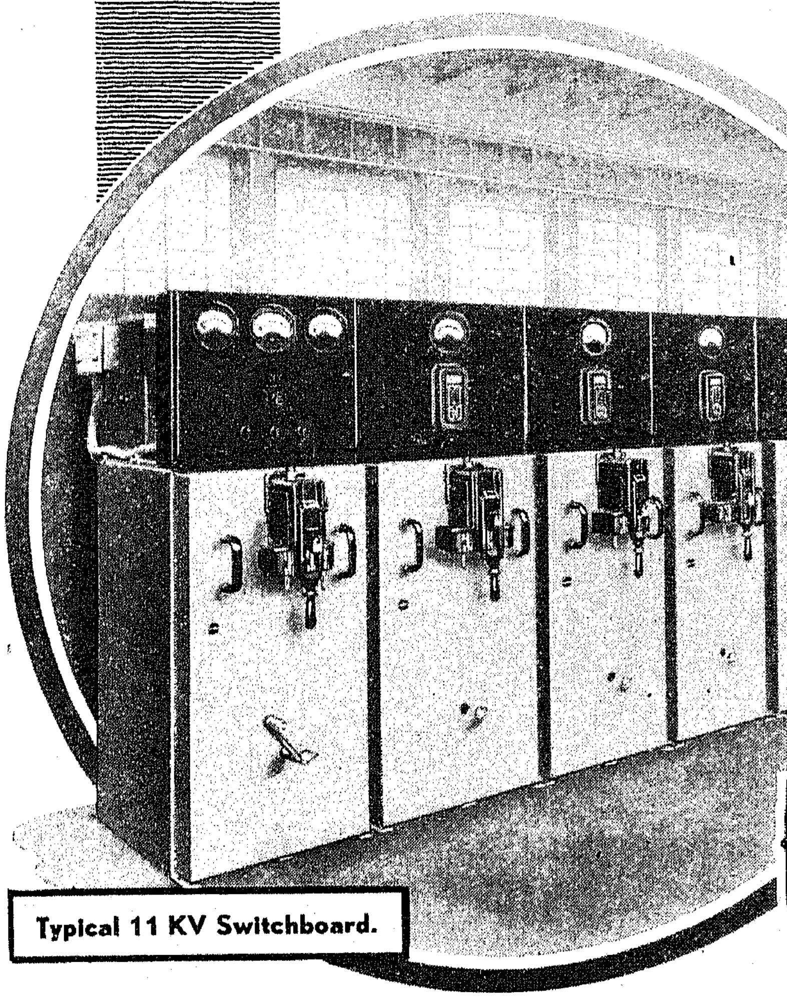

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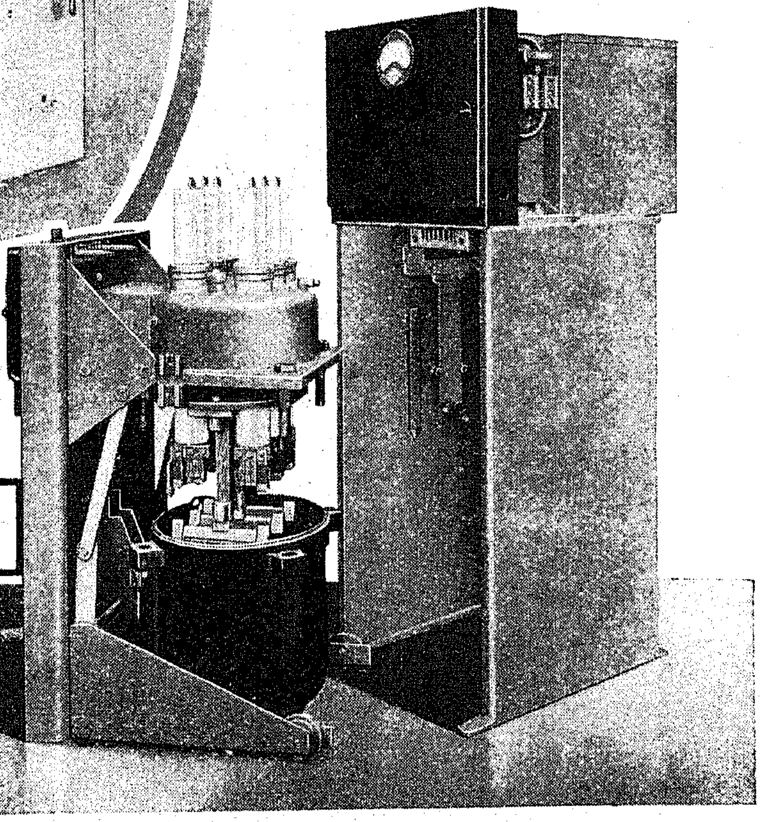

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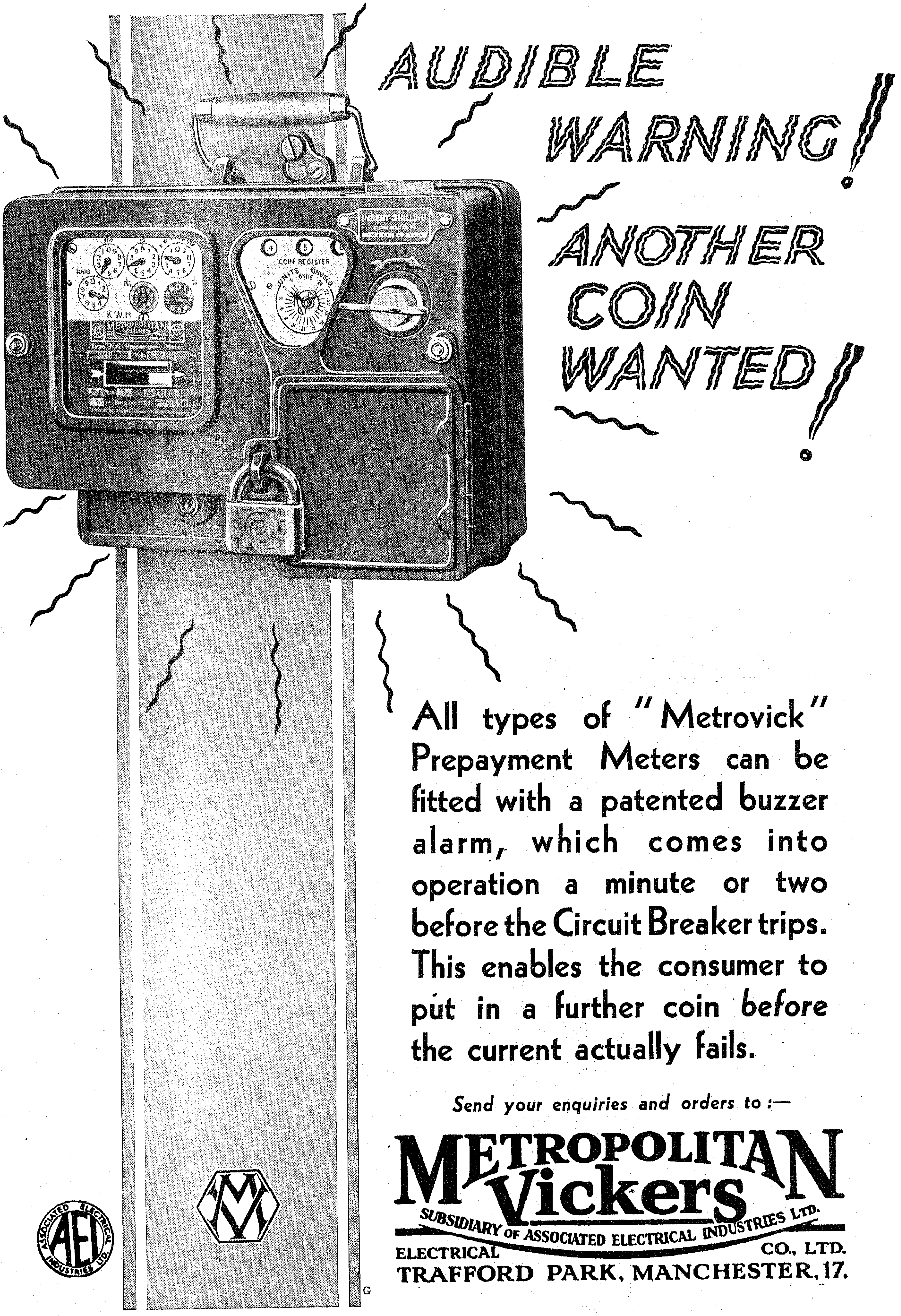

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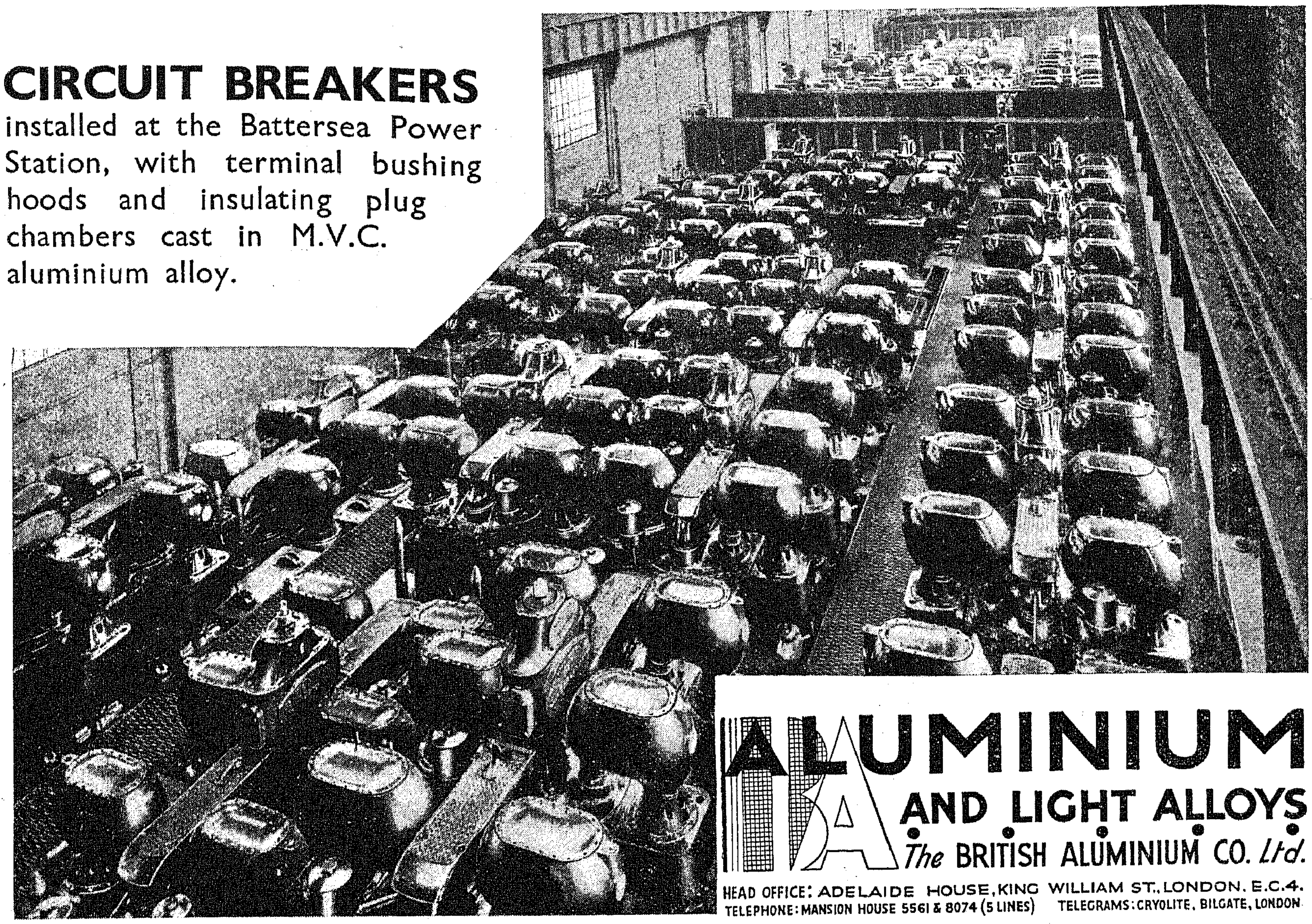

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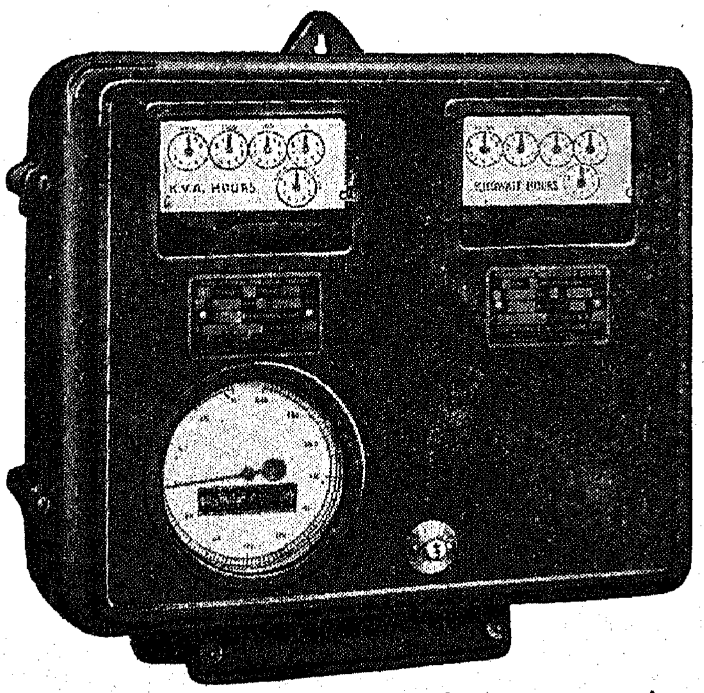

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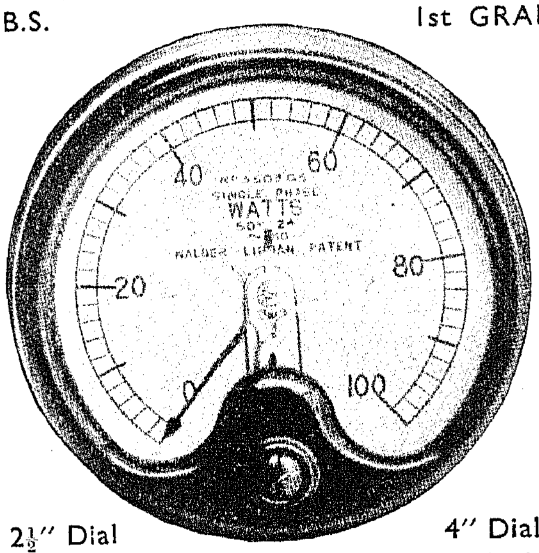

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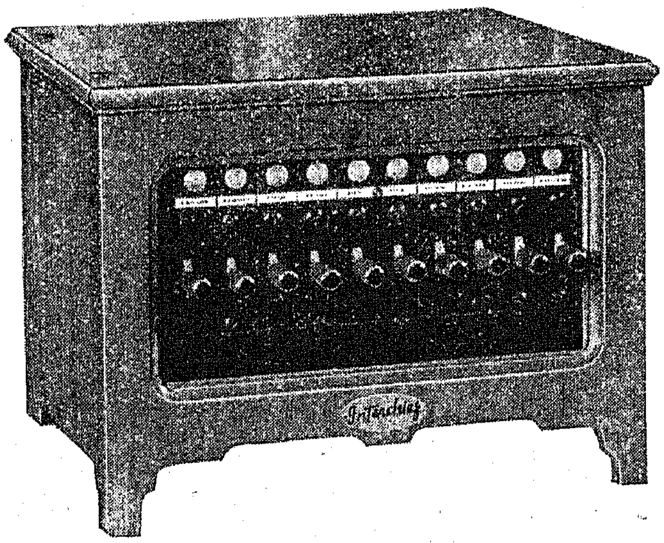

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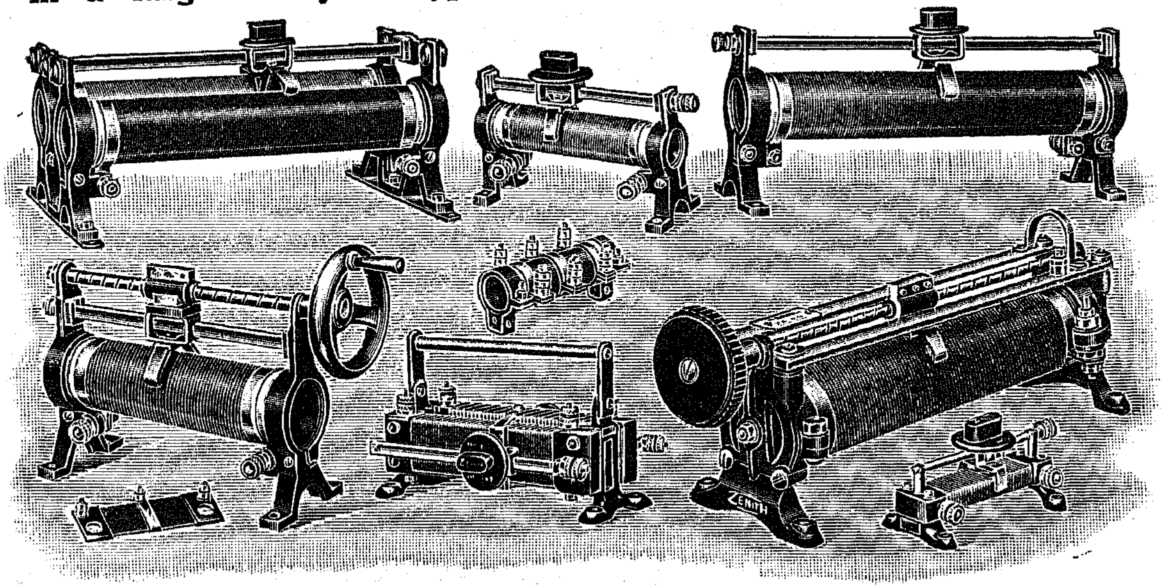

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